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Catch per-Unit-of-Effort in California Waters of the Sardine

(*Sardinops caerulea*)

1932-1942

By

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FOREWORD

This report is the result of a cooperative investigation carried out by the United States Fish and Wildlife Service and the California Division of Fish and Game. Many staff members of both organizations have contributed to the study, both through suggestions of methods of procedure and in the tedious compilations of data and carrying out of the necessary calculations.

We owe much to Mr. O. E. Sette, who proposed many of the adjustments applied to the weekly boat catches and advised freely about their application. Dr. Richard Van Cleve and Dr. L. A. Walford have aided in editing and reviewing the manuscript.

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The Director, United States Fish and Wildlife Service, Department of Interior, has granted permission for publication.

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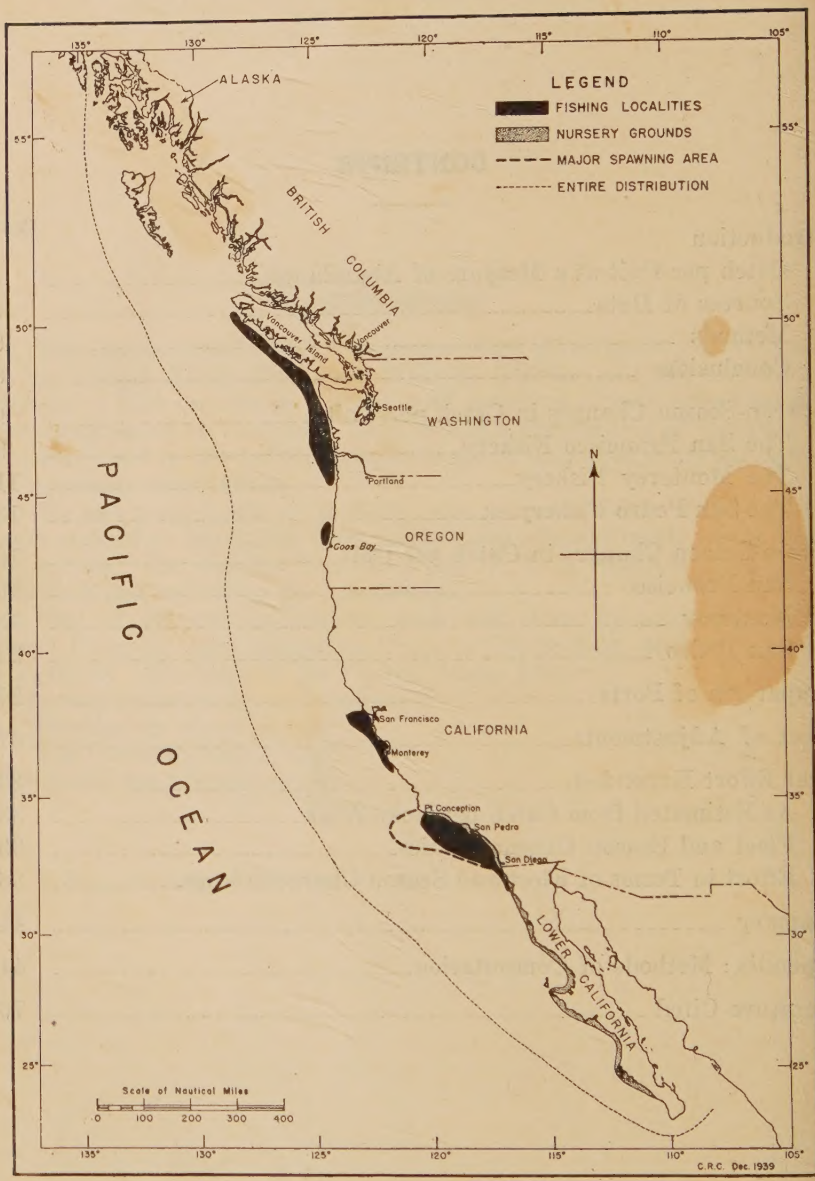

FIGURE 1. Chart of Pacific Coast waters, showing fishing areas, nursery grounds, spawning area, and range of distribution of the sardine.

CATCH PER-UNIT-OF-EFFORT IN CALIFORNIA WATERS OF THE SARDINE, *SARDINOPS CAERULEA*, 1932-42

INTRODUCTION

Catch per-unit as a Measure of Abundance

As is recognized by all fisheries students, the total catch of any species does not usually measure the size of the population available to the fishermen. The size of the total catch depends on the relation between the numbers of fish in the available population and the amount of effort expended. To measure changes in this relationship, the catch per-unit-of-effort has been devised by fisheries workers. Variations in this measure may result either from variations in the size of the total population, from differences in availability of all or a portion of the population to the fishermen, or from changes in the amount of effort expended. For an interpretation of the influence of these factors other sources of information must be drawn upon. The catch per-unit-of-effort is an essential tool, however, in the solution of the vexing problems of fisheries management.

For the sardine several measures of the catch per-unit-of-effort have been calculated. The first to be published was by Hart (1933) and applied to the Canadian fishery off British Columbia. For the time interval studied, 1925-1932, Hart found no significant changes in the return to the fishermen for the amount of effort expended.

In California several preliminary investigations yielded no dependable results, due to the fact that the supply of sardines off the California coast exceeded the demands of the industry to such an extent that catch limits were imposed on individual boats. Any changes in the return per-unit-of-effort merely reflected, therefore, increasing demands of the industry, which resulted in higher catch limits. By the early 1930's, however, the California sardine industry had expanded to the point where it showed evidence of utilizing a large part of the available supply. Clark (1939), therefore, made a study of the return per lunar month for the Monterey and San Pedro fisheries. That investigation showed significant fluctuations with a maximum availability of the sardine population in 1934-35 and then a decline to a lower level in the succeeding seasons. In that investigation no attempt was made to correct for time lost to the fishermen due to unfavorable weather or to adjust for the effect of "limits" imposed on the fishing boats by the processing plants. Under good fishing conditions the fishermen can catch more fish than can be handled by the plants. To prevent gluts the processors limit the number of tons which a boat may catch on succeeding nights. Early in the history of the fishery limits were nearly always in effect. In the later years they were less important but still operating to some extent.

Sette and Palmer (ms) next made a study of the San Francisco fishery which supplied the floating reduction plants operating out of that port. This study involved a preliminary analysis of the influence of weather on the catch and used an average weekly catch as the unit-of-effort. The results were in general agreement with the findings of Clark for the ports of Monterey and San Pedro.

For a more thorough understanding of the relationship between the California sardine catch and the amount of effort expended, it was necessary to bring these studies up to date. In addition it was thought advisable to make an analysis of the external influences affecting the catch for which measurements were available. Also, for other studies involving variations in the sizes of fish available to the fishermen, a unit-of-effort covering a short time interval was desired. This study was undertaken, therefore, and so planned that it yielded the average weekly catch in thousands of pounds for the San Francisco, Monterey and San Pedro sardine fisheries. As far as possible this weekly catch was adjusted so as to be freed from the influence of weather, hours of darkness and of limits. The time interval covered is 1932-33 to 1941-42.

Sources of Data

The catch data used in this study were the records collected by the California Division of Fish and Game of the number of pounds in the daily boat deliveries. The adjustments for wind velocity and direction were based on data derived from the daily weather maps published by the United States Weather Bureau. Data concerning the number, time of sets, size of limits and other pertinent data for specific boat deliveries were collected by the staff of the California Division of Fish and Game through personal interviews with fishing captains. For the 1940-41 and 1941-42 seasons the U. S. Fish and Wildlife Service conducted the interviews at San Francisco.

Methods

Fishing for sardines along the Pacific Coast of North America is carried on by roundhaul nets. In the early history of the industry these nets and the boats from which they were operated were small units termed lampara nets and lampara boats (Scofield, 1929, and Fry, 1931). Such equipment is still used in California in the sardine bait fishery. Later the purse seine was introduced. This is a larger and more efficient type of gear.

In California practically all sardine fishing occurs at night when the schools of fish can be located by the luminescence resulting from the movements of fish through the water. This luminescence can not be seen when the moon is shining nor in daylight. The fishermen plan to leave port in time to reach the fishing grounds when darkness falls. The boat cruises until a school of fish is located, then the net is quickly payed out, all or a part of the school is surrounded, and the fish brailed into the hold of the boat. This is termed a set or haul, and takes from one to several hours, depending on the size of the catch, the smoothness of the water and the efficiency of the crew. When a catch is made the boat returns to port the following morning.

In making the present catch-per-unit analysis, the boats involved for the period, 1932-33 to 1937-38, were the same as those used by Clark in her study, except that at San Francisco only boats delivering to floating reduction plants were used. The method of selecting the boats is described in the appendix (p. 45). For subsequent years additional boats were chosen in the same manner. The landings of these boats

comprised 62 to 91 per cent of the total landings at the various ports, except at San Francisco during the seasons 1932-33 through 1937-38, when they comprised 22 to 84 per cent (p. 46, Table 14). The lower percentage for San Francisco resulted from using the boats delivering to floating reduction plants, only. The daily deliveries of the selected boats were recorded in pounds and summed by lunar weeks.

Because the California sardine is caught at night during the dark of the moon, all detailed compilations of boat catches were made by lunar months. During the full moon there are about five nights when no fishing occurs and at the beginning and close of a lunar period, which extends from full moon to full moon, the hours of darkness are limited. To make all weeks comparable, therefore, it was necessary to adjust each week in accordance with the available number of hours of darkness. The method of making this adjustment is explained in the appendix (p. 58).

Adjustments for the effects of weather and of catch limits were also made and detailed methods are given in the appendix (p. 47). The correction for limits is translated into hours of scouting time. Were a fishing boat not limited by the capacity of the processing plant or by the boat capacity, the entire night would be spent in scouting for schools of sardines except for the time utilized in making a set and brailing the fish into the hold of the boat. The adjusted average weekly catch measures the pounds of fish which would have been caught if the time lost due to bad weather and lack of darkness had been of average magnitude and if 100 per cent of the available time had been spent in scouting for sardine schools. To indicate the effect of these adjustments the unadjusted as well as the adjusted average weekly catches are given in each table and figure.

Throughout the history of the sardine fishery, methods of catching the fish have been continually improved. Size of boat and size of net have gradually increased. The purse seine has supplemented the lampara net, diesel oil has replaced gasoline as a fuel, mechanical devices have been introduced which hasten the setting of nets and brailing the fish onto the boats, and radio telephones have enabled the fishermen to help each other in locating sardine schools. None of these changes has come suddenly, consequently it is not possible to select any time interval and assume that the unit of effort expended has been constant in that interval. Insofar as addition of new boats to the fleet is concerned, this difficulty has been overcome by comparing the weekly catch of any boat in a given year with the catch of the same boat in the previous year. Where improvements have been made on existing boats, or where crews have changed, the difficulty still remains, however, and may have introduced inaccuracies into our measure of catch per-unit-of-effort. For the within-season changes, comparisons were always made between the same boats in any two successive weeks. Throughout the 10 seasons covered in this study boats were entering and leaving the fishery. This necessitated the linking of each season's average catch with the preceding season's. For this linkage 1932-33 was used as the base season for Monterey and San Pedro and 1935-36 for San Francisco. Similarly, for the within-season changes the first week of the season was used as the base week.

The entrance of the United States into the second World War in December, 1941, had a profound effect on the California fishery. Free movement of the boats into and out of ports was immediately stopped. Scouting for fish was curtailed due to danger from submarine activity, and some fishing grounds were closed in the interests of national defense. Because of these extraneous factors this study was terminated with the 1941-42 season. Special methods of analysis may have to be devised to bridge the gap between the prewar and postwar fisheries.

Conclusions

This study has shown that the same changes in average catch per-boat-week have occurred in all of the major sardine fisheries of California. This furnishes additional confirmation to the findings from other lines of investigation which demonstrate that the San Francisco, Monterey, and San Pedro fisheries are all drawing from the same population.

The maximum level of catch per-boat-week occurred in 1934-35, and the lowest level in 1937-38; in the succeeding seasons it was greater than that for 1937-38, but did not again reach the 1934-35 average (Fig. 12). The within-season comparisons of the catch per-boat-week show that the central California fishery receives its best returns from a week's fishing in the fall months (Figs. 6 and 8). For San Pedro in the first half of the time interval the best return to the fishermen occurred in the winter. In the later seasons the catch per-boat-week was higher in the fall (Fig. 10).

The elaborate adjustments made in the weekly boat catch had very little effect on the result in any of the three ports. This would indicate that presence or absence of schools of sardines on the fishing grounds is the chief factor in determining the return to the fishermen for his season's fishing. The effects of weather, hours of darkness and limitation of catch are either random in character and average out, or they are nonrandom but our methods of adjustment have not successfully eliminated their influence. There are sufficient differences between the adjusted and the unadjusted figures, however, to indicate that the adjustments have brought about some changes.

For the present uses of the boat catch analysis the differences between the adjusted and unadjusted results are not great enough to affect their interpretation. Such adjustments would be important if measures of a higher degree of accuracy were justified or if they were to be applied to time intervals shorter than a week.

BETWEEN-SEASON CHANGES IN CATCH PER-UNIT

The San Francisco Fishery [1]

As a sardine fishing port, San Francisco is much younger than e other two considered in this study. The California sardine fishery an industry of importance began in the 1916-17 season, but San ancisco landings were not important until 1926-27; not until 1930 d they constitute as much as 10 per cent of the total for California cofield, 1937, Figs. 4 and 6), although more recently they have run as gh as 50 per cent.

Because of the recent development of the San Francisco fishery, ly intermittent sampling was carried on there during the first few asons covered in the present analysis. Interviews sufficiently numer- s to serve as the basis for the type of adjustments described herein ppendix, p. 47) were not started until the 1935-36 season, and as a sult only unadjusted data are available for the San Francisco seasons, 32-33 through 1934-35. It will be seen (Fig. 2), however, that the adjusted data in general correspond well with the adjusted; for this ason general conclusions may be based on the former for the period, 32-33 through 1934-35. In the following discussion it is to be under- ood that any statements involving seasons prior to 1935-36 refer to e unadjusted data.

Referring to the course of the catch per-boat-week for the entire ason (Figs. 2A and B), the change in level between the 1936-37 and e 1937-38 seasons divides the 10 season period into two five-season b-periods. The mean catch per lunar week for the first five-season

TABLE 1

tween-season changes in catch per-boat-week, San Francisco, 1932-33 through 1941-42. Expressed both in numbers and in weight. Unadjusted figures have been weighted to same total for period, 1935-36 through 1941-42, as adjusted figures

Fishing season	Adjusted catch per boat-week				Unadjusted catch per boat-week			
	10,000 fish season	1,000 pounds			10,000 fish season	1,000 pounds		
		Season	Fall	Winter		Season	Fall	Winter
2-33					122	360	321	395
3-34					155	422	336	561
4-35					183	551	587	496
5-36	163	492	600	364	159	467	513	401
6-37	111	343	384	294	150	406	455	338
7-38	72	174	198	145	70	185	197	170
8-39	112	222	204	277	113	246	237	271
9-40	129	280	332	276	130	276	350	229
0-41	121	252	350	157	102	214	326	104
1-42	136	275	383	[1]	118	244	374	[1]

[1] There was no San Francisco winter fishery in the 1941-42 season, as a result of the war.

[1] By the term "San Francisco fishery" we refer to all landings made in the San ancisco Bay region, and to deliveries made to floating plants operating in the vicinity Point Reyes, the Farallon Islands, and Point Montara.

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period was 441,800 pounds, as compared with 233,000 pounds for the second five-season period. This represents a decrease of 47 per cent in return to the fishermen per-unit-of-effort expended. Comparison of

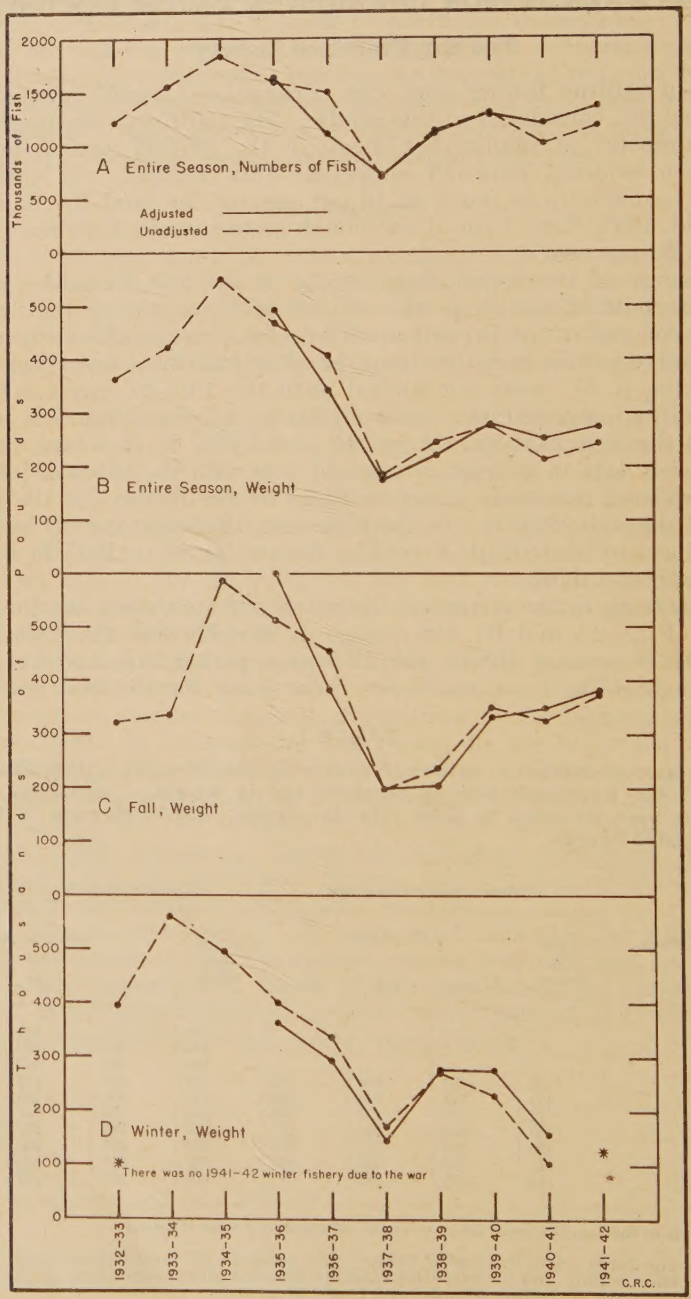

FIGURE 2. Various measures of catch per-boat-week at San Francisco. Unadjusted data have been weighted to the same total for the period 1935-36 through 1941-42 as the adjusted data.

the catch per-unit in numbers (Fig. 2A) with the same statistic in pounds (Fig. 2B) indicates that the decrease was partly the result of a reduction in the average size of the fish. Such a finding is in keeping with the now widely-held theories regarding the relationship between fishing intensity and population characteristics such as that first expounded by Baranov (1918) and simply stated by Thompson (1937).

Considering anomalies from the five-season levels (Fig. 2B), the most striking was the high point attained in 1934-35. It seems most likely that this resulted from the appearance in the catch of one or more dominant year-classes of sardines, which in turn may well have been established by the coincidence of good-sized spawning stocks and hydrographic conditions unusually favorable for the survival of larvae and young fish. Two such length groups are indicated in the length frequencies for the 1934-35 season (Clark, 1939, Fig. 4). Perhaps the high level of that season may have been the result of the combined abundance of these two groups, plus better-than-average availability of schools to the fishermen.

For some time it has been recognized (Andrews, 1928; Clark, 1930, 1936, 1939; Higgins, 1926; Phillips, 1937; Scofield, 1926) that, during the early history of the fishery, at least, the sizes of sardines in the catch changed from one level in the fall to a higher level in the winter. The fishery in the first part of the season, depending on the small sizes of fish, has been termed the "fall fishery"; and that during the latter part of the season, involving the larger fish, has become known as the "winter fishery." Although the two fisheries have not been as well differentiated in recent seasons as in the past, it is of value to consider them separately in order to bring out certain features of the trends. For analysis of length frequencies the separation has been made on the basis of size of fish in the catch (Clark, 1936, p. 9), but in applying it to catch per-unit data it was necesary to make an arbitrary division on the basis of time (Clark, 1939, p. 16). The division as made for Monterey was adopted for San Francisco, since the geographical proximity of the two ports makes their biological seasons similar. Thus lunar months "August" through "November" constitute the fall fishery and lunar months "December" and "January," the winter fishery (appendix, Table 15). It will be noted (Fig. 2D) that there was no winter fishery during the 1941-42 season, because of the war.

Comparison of the trends of the fall and winter fisheries for San Francisco (Figs. 2C and D) shows considerable differences between them. Whereas the catch per-unit-of-effort in the winter (Fig. 2D) declined consistently from 1933-34 to 1941-42 (with the single exception of the increase from 1937-38 to 1938-39), there was an apparent recovery of the fall fishery subsequent to 1937-38 (Fig. 2C).

The Monterey Fishery

As might be expected from the fact that their fishing grounds overlap, Monterey and San Francisco have similar trends of catch per-boat-week. For Monterey, the more complete data available made it possible to add three seasons, 1932-33 through 1934-35, to the adjusted series of catches per-boat-week. The entire-season trends for the period, 1932-33 through 1941-42, are shown in figure 3A and B. As at San Francisco, the two five-season levels may be compared by computing the

arithmetic mean catch per-boat-week for each. This computation yielded means of 480,200 pounds for the first five seasons, and 270,400 pounds for the second five, a decrease of 44 per cent. This is in close agreement with the decrease of 47 per cent for San Francisco, although the absolute level was higher for Monterey for both periods.

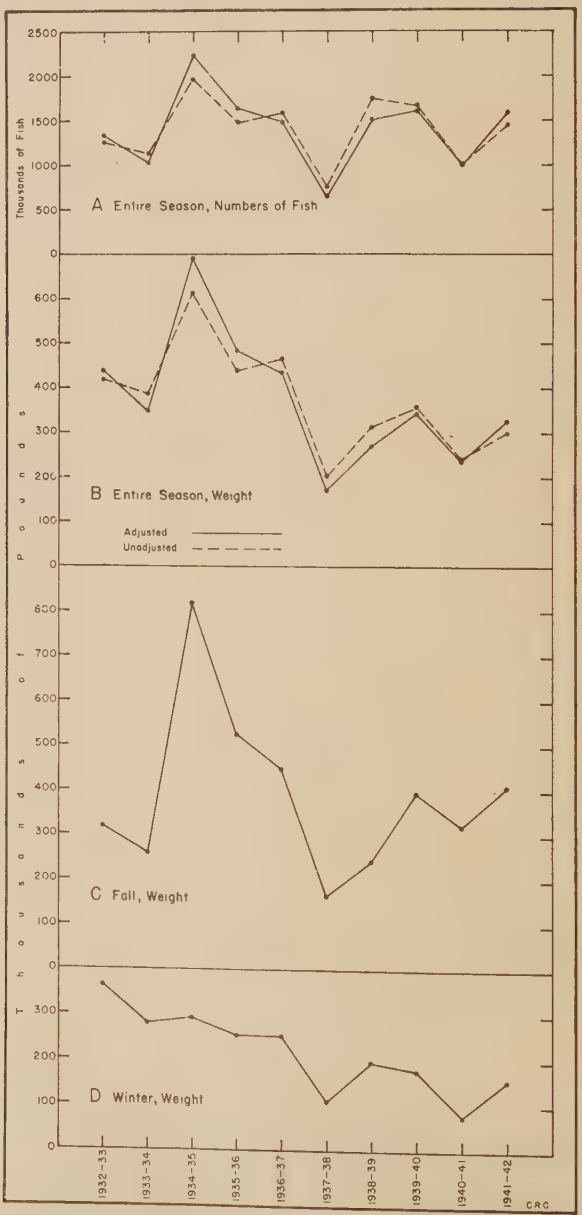

FIGURE 3. Various measures of catch per-boat-week at Monterey. Unadjusted data weighted to the same total as adjusted.

Comparison of the trend by numbers (Fig. 3A) with that by weight (Fig. 3B) indicates that, as at San Francisco, the change in level of catch per-boat-week resulted chiefly from a decrease in the average size of the individual fish.

One of the most interesting aspects of the comparison of the Monterey fall and winter trends (Fig. 3C and D) is the great height of the 1934-35 peak in the former, and its almost complete absence in the latter. In other words, the high level of catch per-boat-week attained in the 1934-35 season was the result of good fishing in the fall. If, as has been suggested above, the peak for the season in question is the result of the appearance of one or more dominant year-classes of sardines, the effect should be felt mainly in the fall fishery, which takes mostly the smaller, younger, "entering" classes of fish.

TABLE 2

Between-season changes in catch per-boat-week, Monterey, 1932-33 through 1941-42. Expressed in both numbers and weight. Unadjusted figures have been weighted to same ten-season total as adjusted figures

Season	10,000 fish per boat-week		1,000 pounds per boat-week			
			Entire season		Fall adjusted	Winter adjusted
	Adjusted	Unadjusted	Adjusted	Unadjusted		
1932-33	133	126	440	420	319	365
1933-34	103	114	348	388	260	280
1934-35	223	197	692	615	819	293
1935-36	164	148	485	440	526	255
1936-37	149	159	436	467	449	254
1937-38	65	76	172	205	166	110
1938-39	151	175	272	316	243	196
1939-40	161	167	344	360	396	179
1940-41	100	101	237	242	321	78
1941-42	159	145	327	301	409	156

Another point of interest in comparing the fall and winter trends (Fig. 3C and D) is the greater stability of the latter. This is in agreement with the hypothesis that the influence of the entering year-classes is felt mainly in the fall fishery. The demonstrated differences (Clark, 1936) in abundance of successive year-classes would naturally effect fluctuations in the fall fishery; while the winter fishery, depending on an accumulation of older year-classes, would be more stable.

There is one further difference between the fall and winter fisheries which seems worth attention. This is that the course of the catch per-boat-week in the winter fishery (Fig. 3D) represents almost a continuous downward trend, whereas in the fall the trend was upward after 1937-38 (Fig. 3C), as at San Francisco.

The San Pedro Fishery

The changes which have occurred in the weekly average boat catch for the San Pedro fishery are shown in figure 4 and table 3. Figure 4A gives the return in numbers of fish per average boat-week linked to 1932-33 as a base year. The solid line represents the entire-season trend of the adjusted values and the broken line the unadjusted trend. Figure 4B shows the same comparisons in pounds rather than numbers,

For the entire season the return per-week's fishing increased from 1932-33 to 1934-35 and then declined steadily until 1937-38. In the succeeding years the average weekly catch fluctuated from season to season. As at San Francisco and Monterey the level of return to the

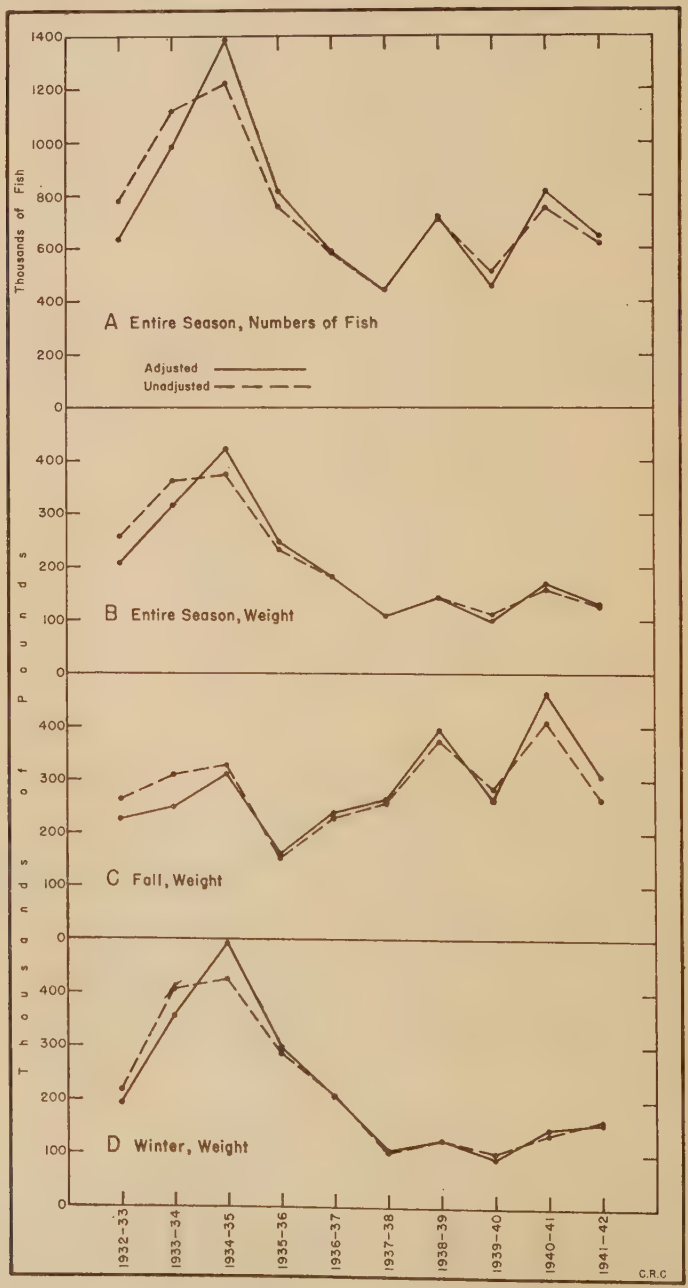

FIGURE 4. Various measures of catch per-boat-week at San Pedro. Unadjusted data weighted to the same total as adjusted.

sherman for his fishing effort was lower in the last five-season interval nan in the first. For the adjusted data the average weekly boat catch or the first five seasons was 274,000 pounds and for the second 130,000 ounds. This represents a decrease of 53 per cent in the level of avail- bility of sardines to the San Pedro fishermen, and a greater decrease nan for the other two ports.

TABLE 3

easonal average pounds and number of fish per-boat-per-week taken in the San Pedro fishery from 1932-33 to 1941-42, linked to 1932-33. Unadjusted figures are weighted to same 10 season total as adjusted figures

Season	Thousands of pounds						Thousands of fish	
	Entire season		Fall fishery		Winter fishery		Entire season	
	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted
32-33	206	252	226	263	194	218	633	780
33-34	315	356	249	310	357	406	985	1,119
34-35	422	369	312	329	493	426	1,389	1,223
35-36	246	228	161	158	299	287	816	759
36-37	183	180	239	229	206	208	590	584
37-38	108	106	263	257	106	103	446	442
38-39	144	141	394	373	126	125	720	712
39-40	99	110	260	282	91	101	459	513
40-41	170	156	462	408	147	137	815	752
41-42	131	125	306	263	157	162	648	620

This decline was greater when measured in pounds per week than n numbers per week. In contrast to San Francisco and Monterey, owever, figure 4A also shows a lower level in catch per-boat-week vhen measured in numbers of fish caught. For the first five seasons he weekly average catch was 882,000 fish and in the second five seasons 18,000. This is a decline of 30 per cent and indicates that the decrease n the average weekly catch measured in pounds results in part from decrease in the size of individual fish and in part from a decline in the evel of availability of sardines.

In figures 4C and D the weekly boat catches for the fall and winter isheries at San Pedro are shown. October to December comprise the all fishery in southern California and January to March the winter ishery. The return per-week's fishing during the winter months fol- owed the same general pattern as that for the entire season but in the fall ishery the trend was reversed, and short-time fluctuations were more iolent. In addition there was a fairly consistent increase after 1935-36 n the average return to the fisherman for his week's fishing. This indi- ates an increase in the recruitment of younger fish which support the all fishery. On the other hand the low level during the winter months or the last five seasons indicates a decrease in the stock of larger, older ish. This is substantiated by length measurements of samples of sar- lines taken daily or semiweekly from the catch. Figures 4A and B show, owever, a decrease in average numbers as well as average pounds of fish aken per-week, and imply that the level of recruitment has not been high nough in the San Pedro region to offset the decrease in the numbers of large fish, as occurred at San Francisco and Monterey.

WITHIN-SEASON CHANGES IN CATCH PER-UNIT

San Francisco

On the whole, the within-season comparisons of catch per-boat-week show less marked changes than do the between-season comparisons. This is particularly true of San Francisco, as illustrated in figure 5. Examination of it reveals no such consistent seasonal variations as have been found in average length of fish. In particular, there is no evident change in level of catch per-boat-week at the time of the transition from "fall" to "winter" length categories, which most often occurs at San Francisco during calendar months, October, November, and December (Clark, 1936, Table 1). This period corresponds roughly with lunar months "October" through "December," yet the graphs in figure 5 show no consistent within-season changes in level of catch per-boat-week

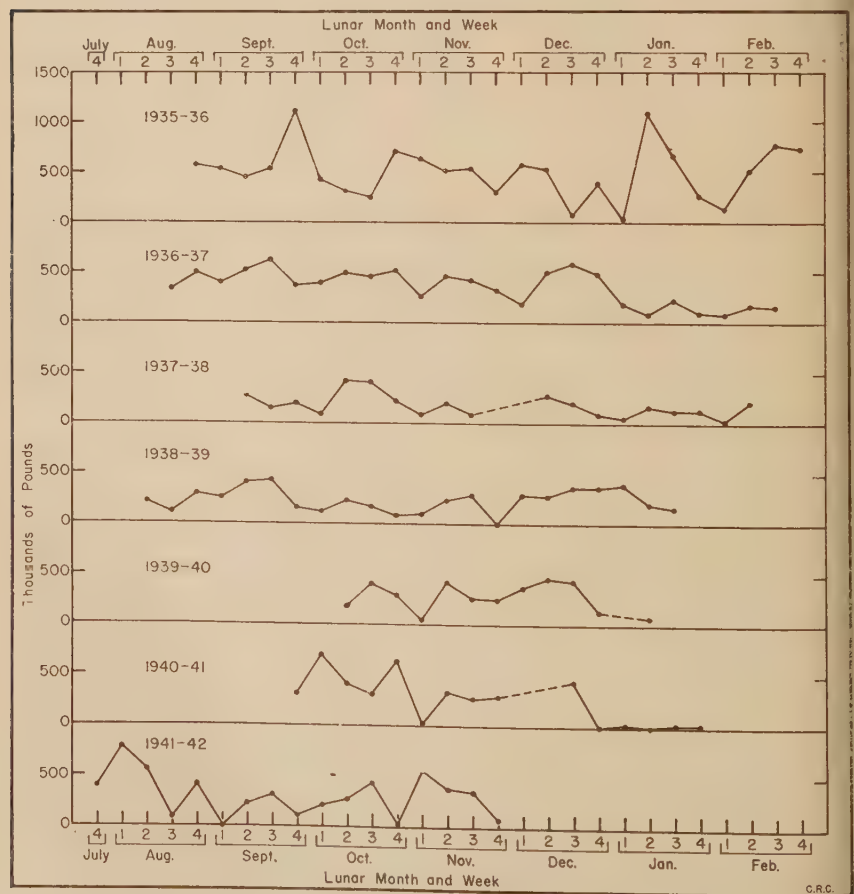

FIGURE 5. Within season changes in catch per-boat-week at San Francisco. Broken lines represent linkage over intervals when less than 10 boats were fishing.

during those months. The seven season average, however, shows a slight decrease in January and February (Fig. 6). It seems likely that most differences in abundance between fall and winter fish are masked by greater fluctuations in availability of schools to the fishermen.

One feature which is brought out in figure 5 is the decrease in length of fishing season which occurred during the period of the analysis. It will be noted that there was a consistent trend toward later beginning and earlier ending of the fishery each season from 1935-36 to 1940-41. The 1941-42 season constituted an exception, beginning earlier than any of the others; but also having the earliest ending, as a result of the start of the war in December, 1941. This decrease in length of season will be considered further in the section "Total Effort Expended."

TABLE 4

Within-season changes in catch per-boat-week, San Francisco 1935-36 through 1941-42. Blank weeks are those during which less than ten boats fished. Data are adjusted

Lunar week		1,000 pounds per boat-week for season							Average 1935-42[1]
		1935-36	1936-37	1937-38	1938-39	1939-40	1940-41	1941-42	
"July"	4							396	
August"	1							792	
	2				212			562	
	3		340		116			88	181
	4	580	504		296			410	448
September"	1	532	396		262			4	298
	2	448	522	274	412			220	375
	3	542	628	148	434			316	414
	4	1,110	372	196	166		310	116	378
October"	1	428	394	82	126		696	214	323
	2	316	500	420	234	184	418	274	335
	3	252	464	412	172	412	312	432	351
	4	708	528	230	90	294	640	24	359
November"	1	644	266	84	100	46	28	558	247
	2	510	468	200	234	422	342	376	365
	3	544	430	82	288	258	268	348	317
	4	300	320		2	244	284	78	205
December"	1	576	190		290	376			358
	2	520	506	270	276	464			407
	3	76	582	204	368	440	432		350
	4	388	490	88	368	140	6		247
anuary"	1	42	190	48	392		26		140
	2	1,092	88	162	196	76	0		269
	3	666	228	122	158		24		240
	4	262	106	120			24		128
February"	1	136	84	20					80
	2	510	174	210					298
	3	772	158						
	4	736							

[1] Weeks represented by less than three seasons have been omitted.

In an attempt to bring out any consistent within-season changes which might exist, the seasons represented in figure 5 were averaged to determine an "average season." The result is shown in figure 6. One readily apparent characteristic is the lunar-month fluctuation, not entirely removed by the adjustments applied. Outside of this the only

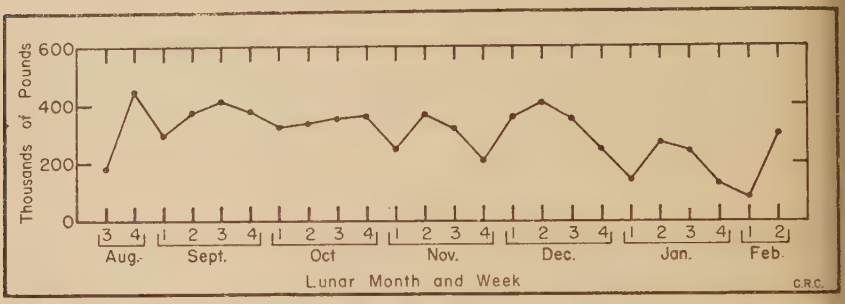

FIGURE 6. Average catch per-boat-week, San Francisco, 1935-36 through 1941-42. Weeks represented by less than three seasons are excluded.

outstanding feature is the falling off in level of catch per-boat-week which occurs in lunar months "January" and "February." This may be connected with the fact that spawning, which takes place chiefly south of Point Conception (Fig. 1) begins in February, and the fish may be migrating from the San Francisco area toward the spawning grounds.

Monterey

Some of the Monterey within-season trends, particularly those for the earlier seasons, have characteristics not apparent at San Francisco. These characteristics give some indication of the way in which the schools of sardines became available to the fishery during the different seasons. Two simple ways in which the fish might become available are as follows: (1) the entire stock might become available at the beginning of the season, and be gradually reduced during the season by the fishery, natural mortality, and emigration, (2) immigration to the available stock and removal by the fishery and emigration take place at a uniform and equal rate throughout the season, so that the level of the stock remains unchanged. Examination of the seasons represented in figure 7 reveals examples seeming to reflect various intergrades of each of the two situations. We may select for consideration two seasons representing extreme examples.

The 1934-35 season, with the exception of two weeks at the beginning, has the typical downward exponential trend which might be expected in a stock being reduced at a constant percentage rate. The individual weekly values (excluding the first two) were plotted semi-logarithmically, and fitted with a straight line by the method of semi-averages. Its slope indicated a decline of about 6 per cent per week or 80 per cent for the entire season. This decline may, of course, be attributed either to mortality or net emigration (i.e., excess of emigration over immigration). Since the rate is higher than most of the present estimates of total mortality, it probably represents a combination of both processes.

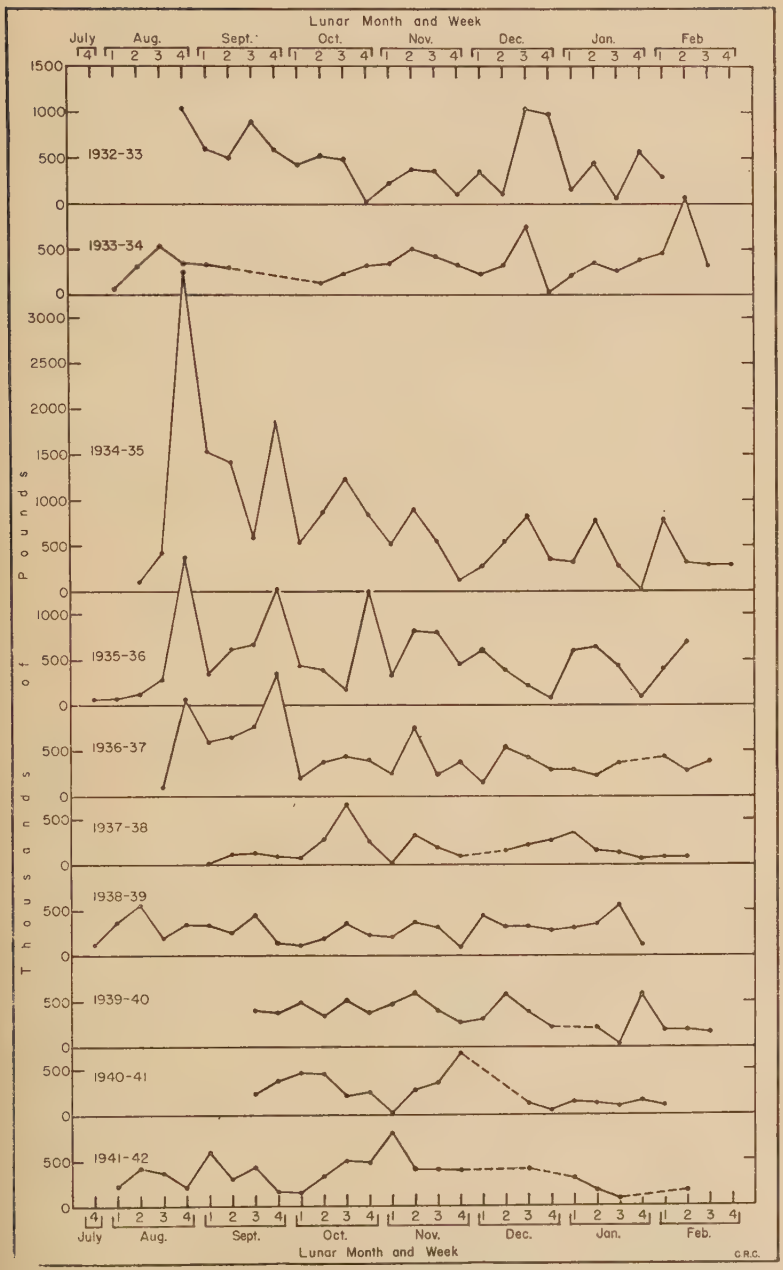

FIGURE 7. Within-season changes in catch per-boat-week, Monterey, 1932-33 through 1941-42. Broken lines represent linkage over intervals when less than ten boats were fishing.

TABLE 5

Within-season changes in catch per-boat-week, Monterey, 1932-33 through 1941-42. Blank weeks are those during which less than ten boats fished

Lunar week	Adjusted catch per boat-week, 1,000 pounds, for season:										Averages			Unadjusted average[2,3] 1932-42
	1932-33	1933-34	1934-35	1935-36	1936-37	1937-38	1938-39	1939-40	1940-41	1941-42	1932-37[1]	1937-42[1]	1932-42[2]	
July 4				66			124							
August 1		60		76			375			220	68	298	183	105
2		310	106	122			569			426	179	493	305	341
3		538	428	289	100		198			369	339	284	320	353
4	1,036	347	3,500	1,625	1,080		349			214	1,518	282	1,164	587
September 1	600	332	1,540	348	604	7	343			599	685	316	547	415
2	497	297	1,425	635	651	116	247			270	701	211	517	638
3	899		589	668	758	120	452	397	236	435	728	328	506	525
4	589		1,862	1,275	1,346	90	137	370	377	164	1,268	228	690	478
October 1	429		539	432	200	74	107	487	459	146	400	255	319	274
2	530	135	871	380	369	269	182	342	450	323	457	313	385	585
3	488	243	1,240	170	441	661	352	507	212	500	516	446	481	610
4	29	323	832	1,255	401	247	226	370	245	492	568	316	442	392
November 1	220	352	511	328	248	8	202	472	22	809	332	303	317	263
2	372	508	898	810	753	322	366	588	280	400	668	391	530	688
3	360	427	550	805	234	193	312	397	354	394	475	330	403	546
4	109	343	125	450	381	89	90	266	678	392	282	303	292	272
December 1	328	243	280	614	150		433	301			323	367	336	313
2	109	323	552	382	536	146	308	578			380	344	367	522
3	1,032	747	823	216	425	207	317	377	125	401	649	285	467	572
4	983	43	349	81	283	264	281	210	46		348	200	282	263
January 1	164	228	319	601	287	349	301		136	295	320	270	298	231
2	449	368	781	639	230	149	337	201	128	177	493	198	346	484
3	65	272	272	425	358	128	545	25	100	81	278	176	227	358
4	518	390	9	93		63	114	581	149		268	227	247	248
February 1	297	468	792	397	422	69		171	101		475	114	340	270
2		1,076	318	684	271	78		177		164	587	140	395	373
3		327	286		378			154			330			
4			291											

[1] Weeks represented by less than two seasons are omitted.
[2] Weeks represented by less than two seasons in each of the two five-season periods are omitted.
[3] Weighted to same total as adjusted "Averages, 1932-42."

The level of catch per-boat-week during the 1938-39 season has practically no trend, and may therefore reflect a condition in which uniform immigration balanced uniform mortality and emigration. Since the fleet at Monterey tended to remain relatively constant, and since the fishing grounds cover only a small portion of the area known to be traversed by the sardine schools (Clark, 1940), such a condition may have actually obtained.

Between the two extremes represented by the 1934-35 and the 1938-39 seasons, we have a series of intergrades, as mentioned above. However, the entire 10 seasons may be roughly classified, from inspection of figure 7, into two groups, according to whether they have a declining trend like the 1934-35 season, or no trend like the 1938-39 season. Such a classification, arbitrarily made, places the 1932-33, 1934-35, 1935-36 and 1936-37 seasons in the first group, and the other six in the second. From the adjusted between-season changes (Fig. 3B), it may be seen that the four seasons in the first group have the highest catch per boat-week values of the 10 seasons in the study. In other words, in unusually successful fishing seasons the catch per-boat-week tends to be high in

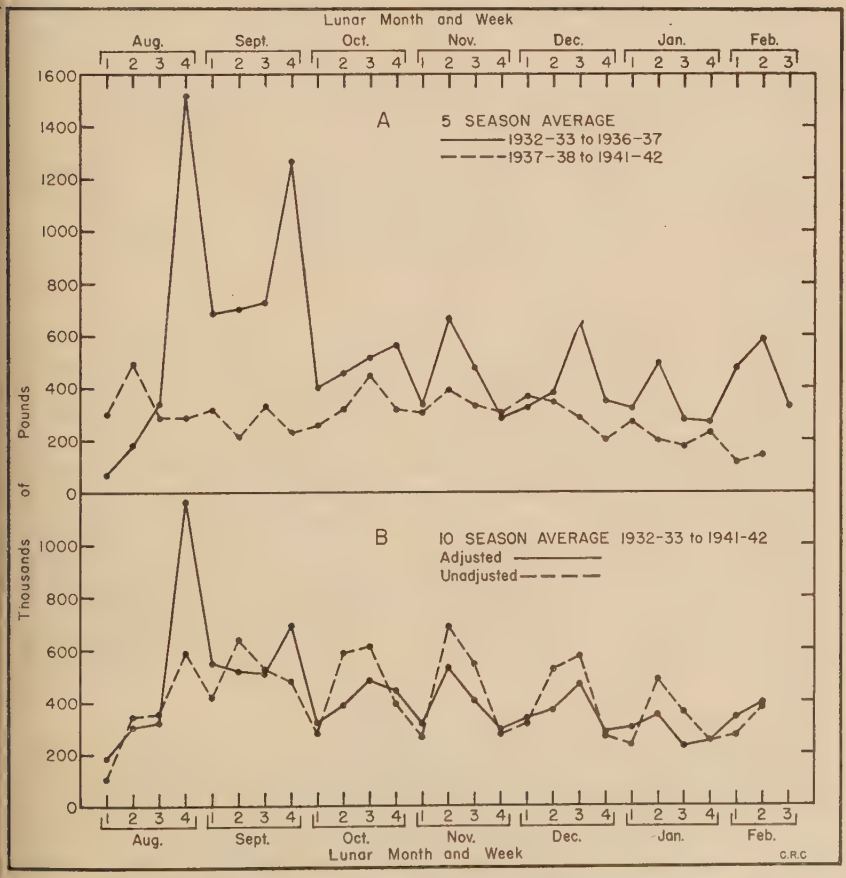

FIGURE 8. Average catch per-boat-week, Monterey, for various periods. Weeks represented by less than two seasons in each five-season period have been omitted. Unadjusted averages weighted to same total as adjusted averages.

the early part (fall fishery) and to decline towards the end of the season (winter fishery). This being true, one would expect to find the level of catch per-boat-week for the entire season more highly correlated with the fall than with the winter level. Such a condition actually obtains, as indicated in figure 3. The coefficient of correlation for the regression of entire season values on fall values is .912, whereas it is only .728 for the regression of entire season on winter. Both of these correlations are significant, the P values being below .02.

Such correlations could result only if the highest level of availability occurred at the beginning of the fishing season. This high level might be brought about either by the early concentration on the fishing grounds of an exceptionally large portion of the sardine population or by the early entrance of new dominant year-classes. In either event the lower level of the winter fishery would result from failure of succeeding immigration to offset the mortality.

In order to bring out any consistent within-season trends, the lunar-weekly catches per-boat-week were averaged for the first and last five seasons of the study, and for the entire 10 seasons. Results are shown in figure 8. Comparison of the two five-season averages again brings out the association of declining within-season trends with high seasonal levels of catch per-boat-week. The much greater within-season decline for the first five seasons than for the last five is readily apparent, and it has already been pointed out under "Between-Season Changes" that the average level of catch per-boat-week was higher for the first five seasons than for the last five. The graph for the last five-season interval shows a decline throughout the months of December, January and February. This is in accord with the between-season trends which indicate a decline in the average weekly catch during the winter months. (Fig. 3-D.)

The average for the 10 seasons (Fig. 8B) exhibits more of the characteristics of the first five seasons than of the last five seasons, because of the greater weight in the average given the former by their higher level of catch per-boat-week. Peaks at lunar weeks "August "-4 and "September"-4 retain their prominence, in contradistinction to the rest of the season, when the weeks near the ends of the lunar months usually marked minima in the curve of catch per-boat-week. Although it will be discussed in more detail under "Effect of Adjustments," it is pertinent to note here that the high level attained near the beginning of the season is brought out only in the adjusted curves. This suggests that the catch during that time may have been held down by some of the factors involved in the adjustments, such as weather conditions, or percentage of night spent scouting. The actual trend of catch per-boat-week, as far as the fishermen are concerned, is only slightly downward.

San Pedro

For the San Pedro fishery the within-season changes are shown in figure 9 and table 6 for each of the 10 seasons used in this study. From 1933-34 to 1936-37 the weekly average boat-catch was greater during January and February than in November and December. In 1932-33 and from 1937-38 to 1939-40 the return to the fishermen for a week's fishing showed no definite trend throughout the season but in 1940-41 and 1941-42 the fall fishery exceeded that of the winter.

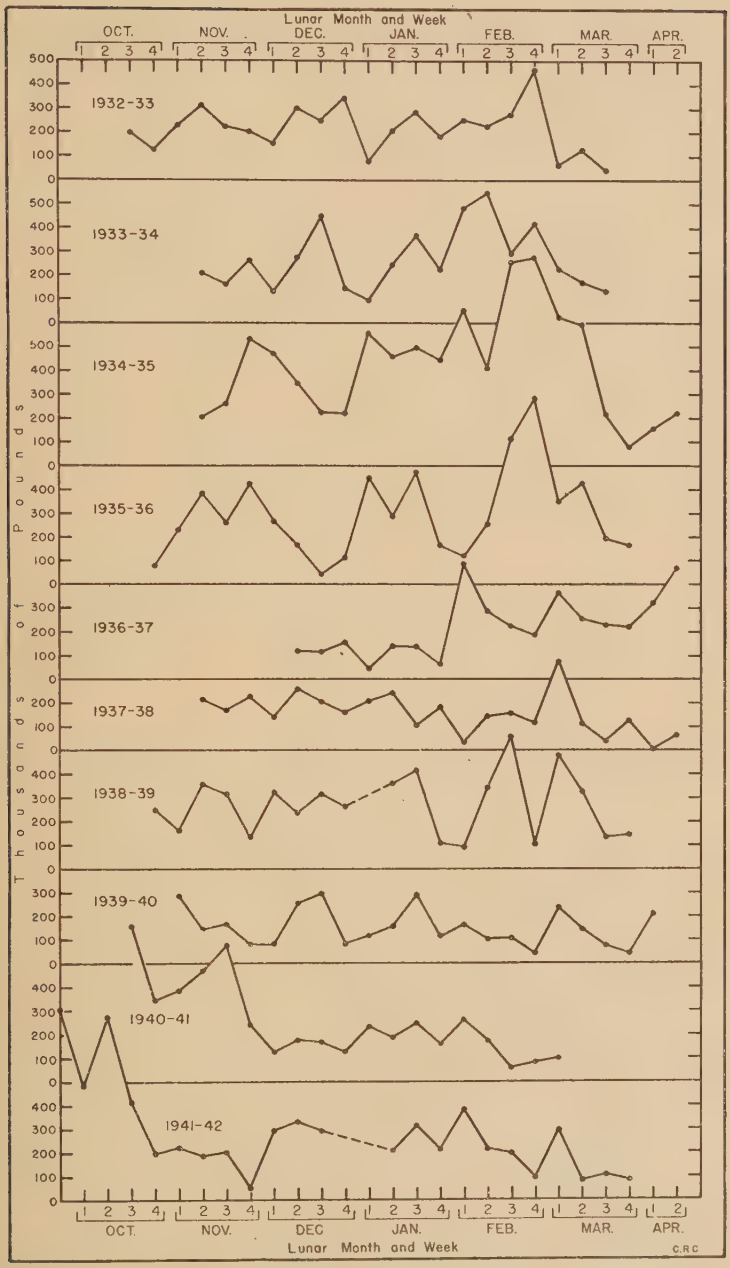

FIGURE 9. Within-season changes in catch per-boat-week, San Pedro, 1932-33 through 1941-42. Broken lines represent linkage over intervals when less than 10 boats were fishing.

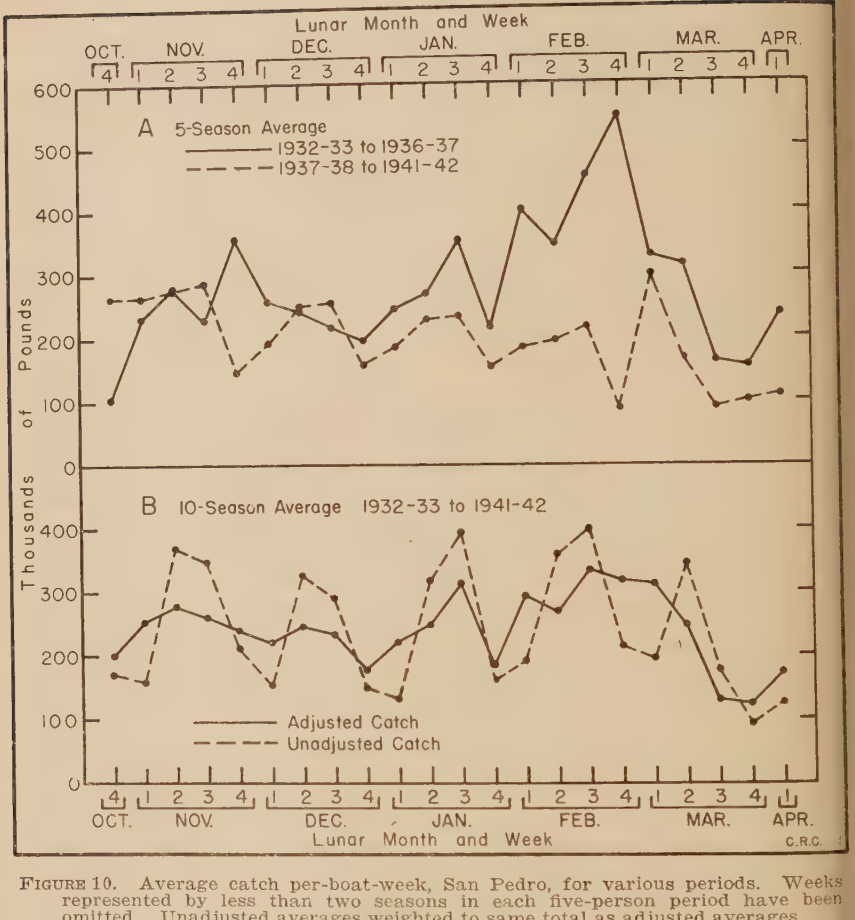

FIGURE 10. Average catch per-boat-week, San Pedro, for various periods. Weeks represented by less than two seasons in each five-person period have been omitted. Unadjusted averages weighted to same total as adjusted averages.

The reversal of the seasonal trend is shown more clearly in figure 10A. The five seasons, 1932-33 to 1936-37, are averaged and compared with the average for the five seasons, 1937-38 to 1941-42. Such a change in the success of the winter fishery relative to the fall fishery was not evident in a similar comparison for Monterey (Fig. 8A). At San Pedro the weekly average boat catches throughout November and December are similar for the two intervals but the January to March averages are greater during the first five seasons than during the second. This again demonstrates that the decrease in return-per-unit-of-effort expended has occurred in the winter months when the San Pedro fishery depends on larger sized sardines (Fig. 4).

In figure 10B are shown the 10-season average weekly catches for the adjusted data compared with the unadjusted. For the 10 seasons the success of the fishing boats was somewhat greater in January and February than in November and December. Prior to the past few seasons the San Pedro sardine fishermen experienced their best fishing during the winter months. This was true also in the decade preceding this study.

TABLE 6

Average weekly catch per boat in thousands of pounds for the San Pedro fishery from 1932-33 to 1941-42

Lunar week	Adjusted catch per boat-week, 1,000 pounds, for season:										5-season average		10-season average	
	1932-33	1933-34	1934-35	1935-36	1936-37	1937-38	1938-39	1939-40	1940-41	1941-42	1932-33 to 1936-37	1937-38 to 1938-39	Adjusted	Unadjusted
September 4										805				
October 1										485				
2										776				
3	200								658	415				
4	130			80			248		342	199	105	263	200	170
November 1	230			231			161	288	385	223	231	264	253	158
2	314	211	207	383		216	359	144	467	189	279	275	277	370
3	226	163	262	260		169	315	167	578	202	228	286	260	348
4	205	265	533	425		227	132	81	240	51	357	146	240	212
December 1	157	136	470	268		140	322	81	123	296	258	192	221	154
2	301	272	348	164	120	260	234	252	175	331	241	250	246	326
3	250	450	223	41	115	206	314	296	165	292	216	255	235	290
4	345	145	220	112	156	160	262	82	126		196	157	179	149
January 1	80	98	558	450	45	207		118	231		246	185	223	133
2	207	245	460	287	140	240	360	154	183	208	268	229	248	318
3	286	368	497	473	138	105	416	289	245	316	352	234	313	393
4	183	224	443	162	62	181	107	111	158	215	215	154	184	161
February 1	252	483	656	119	488	32	91	163	261	381	400	185	292	192
2	226	549	409	252	287	141	340	102	172	215	345	194	269	359
3	275	294	859	612	224	157	557	105	59	199	452	216	334	399
4	462	418	878	784	187	118	103	44	80	94	546	88	317	215
March 1	64	228	625	349	364	378	479	236	98	297	326	297	312	195
2	128	171	593	427	253	113	324	142		81	314	165	248	343
3	43	136	217	190	230	40	134	74		108	163	89	130	176
4			80	164	221	127	144	46		84	155	100	124	92
April 1			154		320	7		211			237	109	173	126
2			220		466	65								

In the recent years, however, winter catches have been much poorer and the industry has relied more and more on the return during the fall months. Because of this decreasing success during the winter months, October was opened to sardine fishing in southern California in 1941-42 and in 1942-43 the month of March closed.

In each of the individual seasons, in both five-season averages and in the 10-season average, the weekly catch declined throughout March. This decline is presumably associated with the onset of the spawning season and the general movement of the sardine population out of the southern California fishing region toward the off-shore spawning grounds. Four of the 10 seasons show a slight upward trend in early April. The boat catches on which these weekly averages are based are few in numbers, however, and this paucity of data precludes any conclusions about changing levels of availability at the termination of the San Pedro sardine season.

COMPARISON OF PORTS

To facilitate the study of similarities and differences between the three major sardine fishing ports, the catches per-boat-week are compared in figure 11. For the entire season the trends, shown in figure 11A, indicate that all three ports have experienced the same general fluctuations in return per-boat-week. The peak of availability was reached in 1934-35; this was followed by a continuous decline until 1937-38, then a leveling off with minor fluctuations for the remaining seasons. At San Francisco and Monterey the return to the fishermen increased slightly between 1937-38 and 1941-42, whereas at San Pedro there was almost no increase. Although the variations in average weekly boat catch have shown the same trends for the three ports the average catch for San Pedro has been lower throughout the 10 seasons included in this study.

Additional information can be obtained from a comparison of the fall and winter fisheries for the three ports. These trends, which are compared in figure 11B and C, indicate some marked differences in the average weekly catch of the fishermen. The maximum attained in 1934-35 is reflected in the Monterey fall fishery but not in the San Pedro. On the other hand, the San Pedro winter fishery shows this 1934-35 maximum but Monterey does not. After 1935-36 the graphs for all three ports are similar. For central California the average catch per-boat-week during the entire season was largely determined by the success of the fall fishery, whereas in southern California the return during the winter months established the entire season level.

At San Pedro, throughout the fall the average weekly boat catch was less than that for central California until 1937-38. In the succeeding season the general average equalled that of Monterey and San Francisco. Throughout the winter months, on the other hand until 1935-36, the weekly average at San Pedro was on a somewhat higher level than at Monterey. After 1935-36 the San Pedro level fell below that at San Francisco and Monterey. The lower average for the entire season at San Pedro results, therefore, from the poorer returns throughout the fall months in the first part of the time interval and the lesser yield during the winter months in the second part.

These similarities and differences between the three California fishing regions result from the distribution and movements of the sardine population. That the entire sardine population is moving throughout its range has been demonstrated by marking experiments (Hart, 1943; Janssen, 1938; Clark and Janssen, 1945). This means that all of the fisheries along the Pacific Coast of North America are drawing from the same population. The similarities in the major changes in the average weekly-boat-catch at the three California ports reflect, therefore, changes in the entire sardine population.

Within the seasons, however, differences occur which are brought about by annual movements of the sardine population. The San Francisco and Monterey fishermen experience their best fishing between August and November when the smaller and medium sized fish are available in central California. Here the success of the fall fishery chiefly

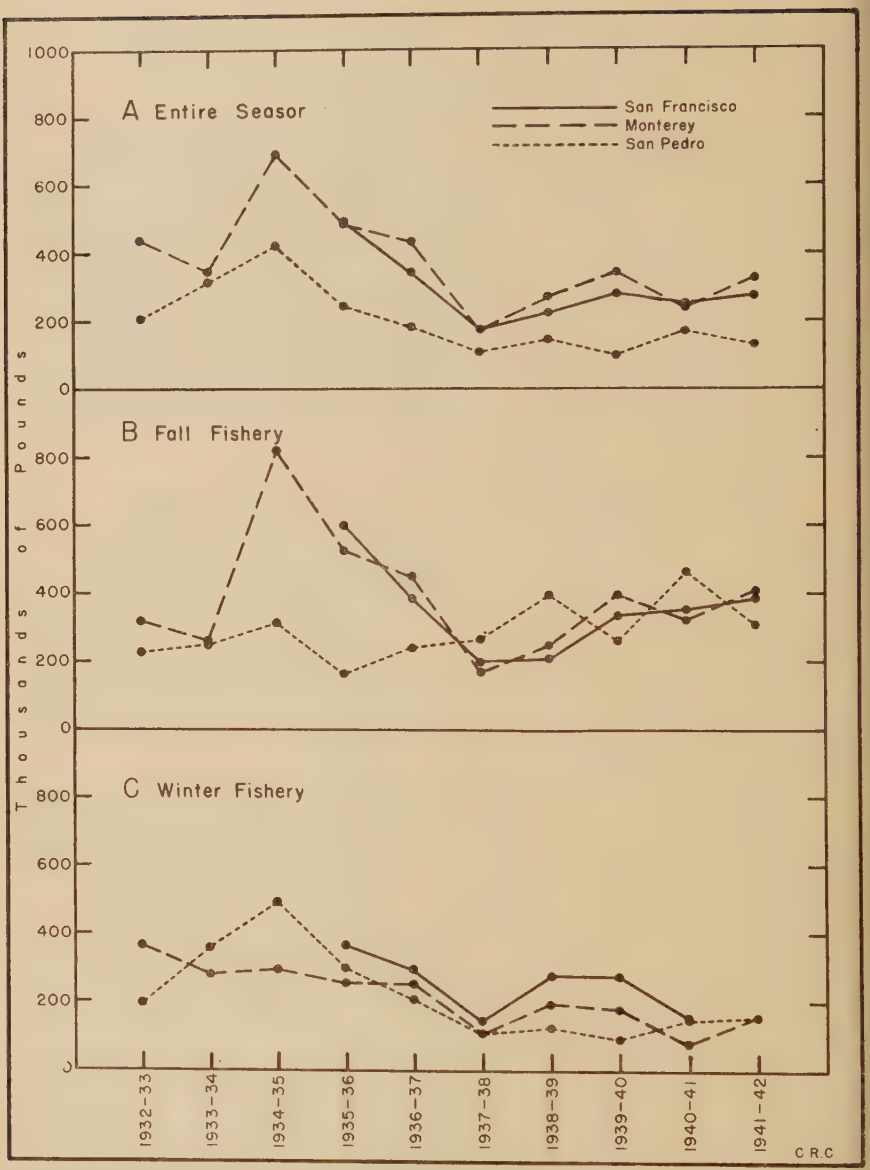

FIGURE 11. Various measures of catch per-boat-week, comparison of ports.

determines the success of the entire season. The larger sardines, on the other hand, are found in central California during December, January and early February. Their stay in central California is much more transitory than that of the smaller sizes during the fall months. Both larger and smaller sardines are present off southern California from January through March, but in the fall, October to December, the catch consists chiefly of the smaller sizes. The presence of both large and small sardines during the winter presumably accounts for a higher level of

return to the fishermen in the earlier seasons of this study. A gradual reduction in numbers of the larger fish in the population has caused the lower level in the winter months in the last half of the 10 seasons studied.

The high level of abundance attained in 1934-35 and maintained to a fair degree in 1935-36 presumably resulted from the successful survival of one or more year-classes spawned a few years previously. This high level occurred in the fall at Monterey, during the winter in southern California, and in both the fall and winter at San Francisco.

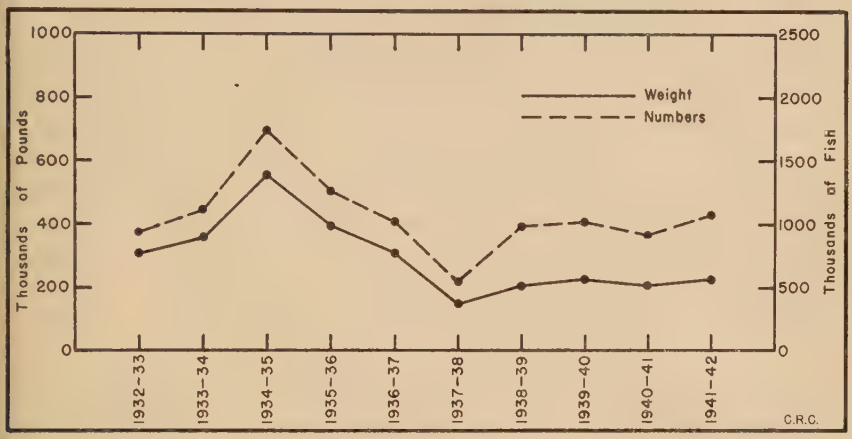

FIGURE 12. Catch per-boat-week, ports combined.

To give a single measure of availability for the entire sardine population the average catches per-boat-week have been combined for the three ports and the result is shown in figure 12. This calculation was carried out by dividing the tonnage of each port per season by the average weekly boat-catch. This gave the total effort expended at each port in terms of number of boat-weeks. The total effort for the three ports was then summed by seasons and divided into the entire State catch, thus

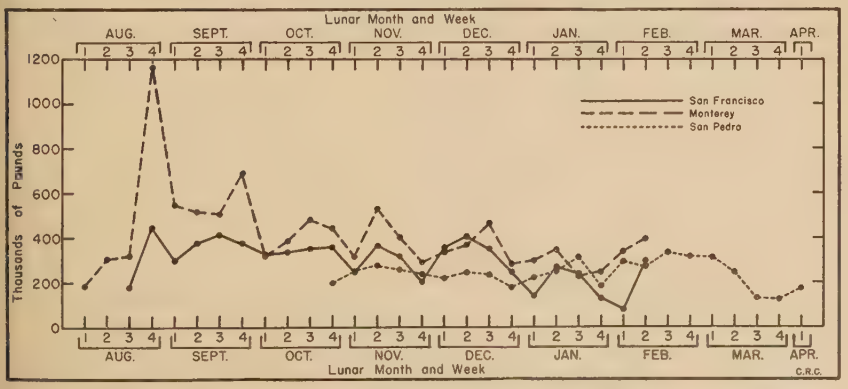

FIGURE 13. Within-season changes in catch per-boat-week. Seven-season average for San Francisco compared with 10-season average for Monterey and for San Pedro.

giving the average weekly boat catch for all the California fisheries. The decline from 1934-35 to 1937-38 is consistent. Since that season there has been little change in the level of abundance expressed in terms of pounds caught. On the basis of numbers of fish caught, since 1938-39 the level has been similar to that of 1932-33 and 1933-34 but not equal to 1934-35 and 1935-36.

TABLE 7

Combined indices of catch per-boat-week for the three California ports. See text for method of combination

Season	Catch per boat-week in units of:	
	1,000's of pounds	1,000's of fish
1932-33	308	939
1933-34	358	1,105
1934-35	554	1,742
1935-36	394	1,260
1936-37	310	1,025
1937-38	150	547
1938-39	206	981
1939-40	228	1,020
1940-41	208	921
1941-42	228	1,075

The within-season changes, for the three ports are compared in figure 13. The San Francisco graph is based on the seven-season average, 1935-36 to 1941-42, and those for Monterey and San Pedro on the ten-season average, 1932-33 to 1941-42. The most striking difference is in the months involved in the fishing season. In central California sardine fishing is carried on from August through mid-February and in southern California from October through March. These seasons although regulated by law, in general constitute the time intervals when fish are available on the fishing grounds in adequate abundance to support the industry.

Throughout the fall months the average weekly catch is greatest at Monterey, and San Francisco occupies an intermediate position between Monterey and San Pedro. In January and February the weekly averages do not differ greatly at the three ports.

EFFECT OF ADJUSTMENTS

In establishing future policies regarding the number of adjustments to be applied, it may become necessary to weigh the amount of labor involved in computing the various adjustment factors against the amount of improvement in the final results accomplished by each. To obtain a preliminary appraisal, the between-season changes for San Pedro were computed on three bases: (1) completely adjusted, (2) adjusted only to remove the effect of varying percentages of night spent scouting, and (3) unadjusted. The results are shown in figure 14. In order to secure a better comparison, each of the three series of figures represented in the graphs was weighted to the same general level.

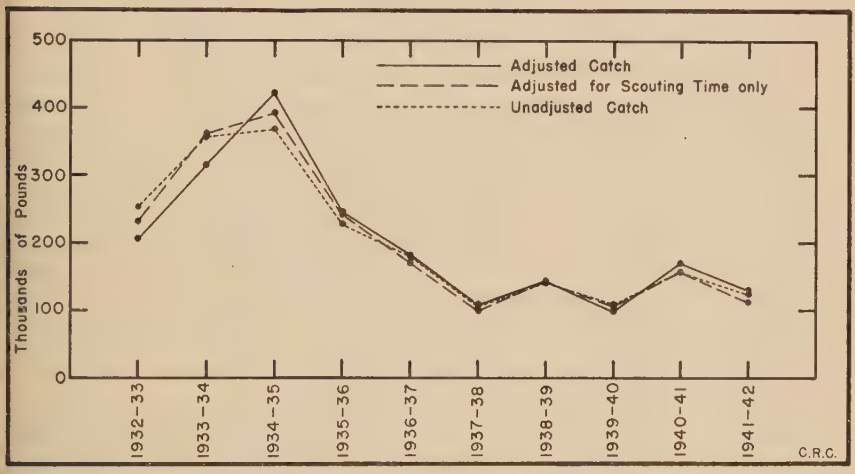

FIGURE 14. Weekly average catch per-boat, entire season average, adjusted for all factors; compared with catch adjusted for scouting time only and with the unadjusted catch. Data for the San Pedro fishery.

This particular comparison indicates that but little change was accomplished by the successive adjustments applied. Such changes as occurred were chiefly in the direction of increasing the differences between catch-per-unit values at high and at low availability levels. The reason for this is obvious in regard to the adjustment for percentage of time spent scouting. Since the unadjusted computations assume that 100 per cent of each night is spent scouting they underestimate changes in catch-per-unit-of-effort between good fishing and poor fishing, for, when fishing is good more time is spent making sets than when it is bad, and as a consequence a smaller percentage of the night is available for scouting. Thus the catch *per-unit-of-effort* (i.e., per unit of scouting time) is higher during good fishing than it appears to be in the 100 per cent scouting time computation. The scouting time adjustment was applied to correct for this effect, and figure 14 indicates that it accomplished some change in the direction of greater differences between high and low catch-per-unit levels.

TABLE 8

Seasonal average pounds per-boat-per-week taken in the San Pedro fishery. Comparison of catch adjusted for all factors with catch adjusted for length of scouting time only and with unadjusted catch

Season	1,000's of pounds per boat-week:		
	Fully adjusted	Adjusted for scouting time only	Unadjusted
1932–33	206	236	252
1933–34	315	361	356
1934–35	422	392	369
1935–36	246	242	228
1936–37	183	170	180
1937–38	108	100	106
1938–39	144	144	141
1939–40	99	106	110
1940–41	170	158	156
1941–42	131	113	125

In addition to the San Pedro test some unadjusted values were computed for the other ports, and are shown in their respective text figures and tables (Figs. 2, 3, 4, 8, 10; Tables 1, 2, 3, 5, 6). Most of these bear out the above statement that the unadjusted data appear to underestimate the changes between high and low levels of availability. As an illustration, we may take the comparison of the two five-season levels of catch per-boat-week at Monterey. It has already been stated (under "Between-Season Changes in Catch-per-unit") that at Monterey the change from the first to the second five-season level, using the adjusted data, represented a decrease of 44 per cent. For the unadjusted results, the comparable result is 39 per cent. At the present stage of development of our use of the catch-per-unit computation, such a difference would not be important. However, it is entirely possible that more refined operations based on measures of catch-per-unit may be carried out in the future, and in such a case differences of the above magnitude might be of consequence. Under such circumstances it would be necessary to establish the significance of the changes effected by the adjustments.

TOTAL EFFORT EXPENDED

As Estimated from Catch per-Boat-Week

Up to this point in the report, the amount of effort expended at the various ports each season has not been expressed in absolute terms. This has been avoided by use of the method of linkage described in the introduction under "Methods." It is desirable, however, to know the absolute numbers of units of effort (boat-weeks) expended, since these statistics are valuable in many studies of the effect of the fishery on the population of sardines.

TABLE 9

Total catch and total effort for the California sardine fishery

Season	San Francisco		Monterey		San Pedro		Three Ports	
	Total catch 1,000,000 pounds	Total effort boat-weeks	Total catch 1,000,000 pounds	Total effort boat-weeks	Total catch 1,000,000 pounds	Total effort boat-weeks	Total catch 1,000,000 pounds	Total effort boat-weeks
1932-33	154	401	180	409	168	816	502	1,626
1933-34	212	475	304	874	250	791	766	2,140
1934-35	370	636	462	668	358	848	1,190	2,152
1935-36	476	968	368	757	276	1,122	1,120	2,847
1936-37	762	2,228	414	950	276	1,516	1,452	4,694
1937-38	402	2,310	210	1,221	220	2,037	832	5,568
1938-39	498	2,223	360	1,324	292	2,028	1,150	5,575
1939-40	424	1,514	454	1,320	186	1,860	1,064	4,694
1940-41	230	913	330	1,387	342	2,012	902	4,312
1941-42	378	1,370	500	1,524	292	2,246	1,170	5,140

Assuming the adjusted catch per-boat-week of the selected boats is representative of the entire fleet and knowing the total catch (Table 9), it is simple to compute the number of boat-weeks expended, by dividing the total catch by the catch per-boat-week (Tables 1 to 3). Amounts of effort computed in this way, and total catches, are shown in figures 15A, B, C. The adjusted, linked, catches per-boat-week were used in making the computations. For Monterey and San Pedro the base season for the linked series was 1932-33, and for San Francisco it was 1935-36. Thus the catches per-boat-week, and the numbers of boat-weeks computed from them, are *in terms of the fleets fishing at these particular ports and in these particular seasons.* Also, since adjusted data were used, the boat-weeks are on the basis of *six full nights of scouting each week.*

Since the numbers of boat-weeks for each port were expressed in terms of its own base-season fleet, the numbers for the three ports are not directly comparable. However, as an approximation of the total amount of effort expended in California as a whole, the numbers of boat-weeks were simply added for the three ports, and the result is shown in figure 15D.

Comparison of the total effort curves for the three ports (Fig. 15A, B, C) reveals some differences. At Monterey there was a fairly continuous increase in effort expended during the period of the study, with

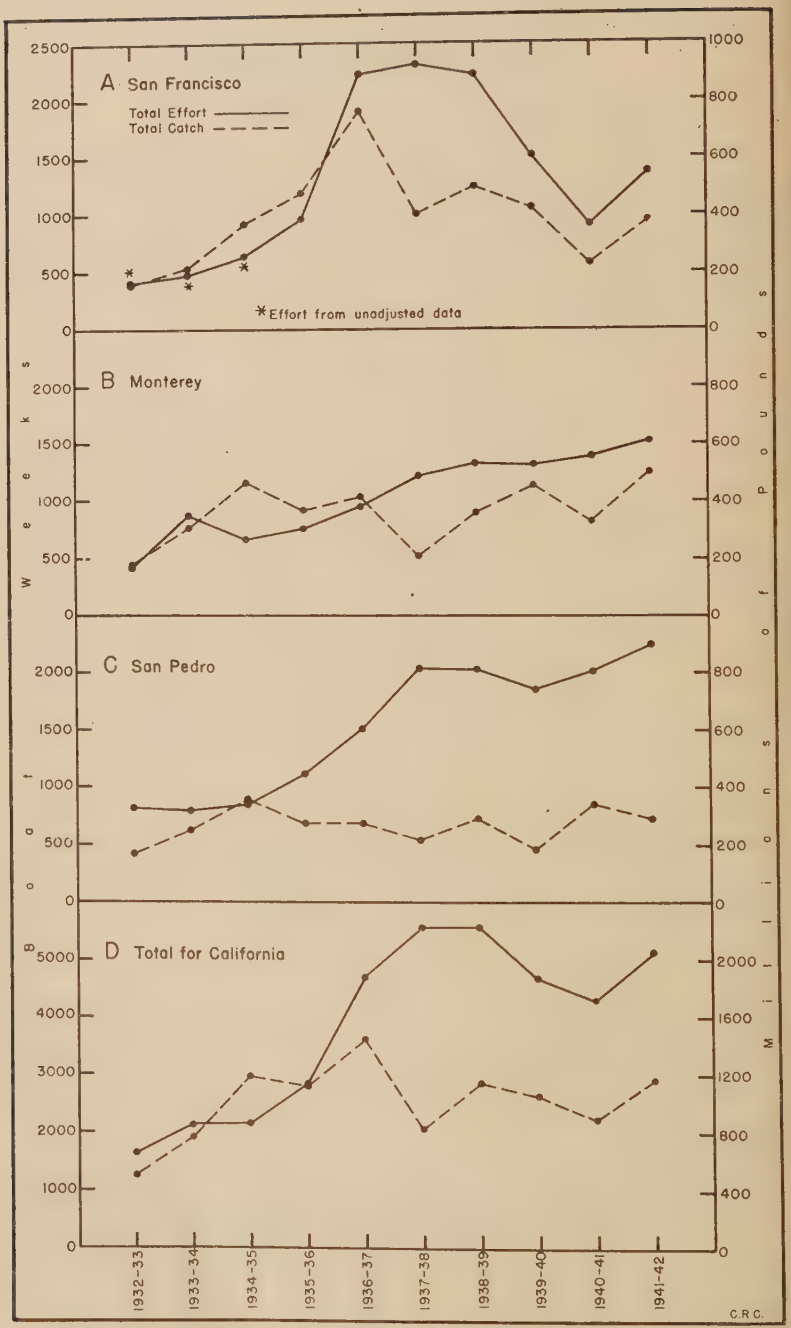

FIGURE 15. Total effort and total catch for the California sardine fishery.

relatively small fluctuations, whereas at San Pedro there was little increase after 1937-38. At San Francisco a transient increase was introduced by the entry of the floating reduction plants into the industry, which caused the sharp rise from 1935-36 to the high level from 1936-37 to 1938-39. For the State as a whole (Fig. 15D) we find that most of the increase in annual expenditure of effort took place between 1935-36 and 1937-38, with somewhat of a decline after 1938-39. These changes resulted largely from variations at San Francisco.

Fleet and Season Characteristics

In the preceding section we obtained a relative measure of total effort in terms of the fleets operating during certain base seasons. If there is to be any control or administration of the fishery, however, it is necessary to have the units of effort expressed in absolute rather than relative terms. In other words, the administrator needs an answer to the question "How much fishing effort can be exerted by a given fleet of boats operating at a certain port for a stated length of season?" Study of this problem was begun under the assumption that the amount of effort expended would be determined largely by three factors: (1) the length of the season, (2) the number of boats fishing, and (3) a physical measurement or combination of measurements of the boats and their gear.

Length of season (Tables 10 to 12) was expressed as the number of lunar weeks at each port during which at least 10 boats from the selected fleet were fishing. Whether or not the boats were fishing was determined by the method explained in the appendix (p. 54).

TABLE 10

San Francisco. Length of season, fleet strength and boat characteristics. Data for seasons 1932-33 through 1937-38 refer only to the fleet delivering to floating reduction plants

Season	Number of lunar weeks[1]	Number of boats in fleet[2]	Boat-length feet		Number of men		Horsepower of engine		Length of seine, fathoms		Depth of seine, fathoms	
			Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean
1932-33	20	19	18	69.2	18	10.2	18	165.0	15	177.7	15	24.5
1933-34	22	16	16	71.2	16	10.3	16	188.4	16	187.6	15	24.7
1934-35	24	26	24	69.9	23	10.3	24	171.9	18	181.3	18	27.4
1935-36	25	32	30	71.6	29	10.3	29	181.9	20	198.0	19	27.2
1936-37	25	60	53	72.5	52	10.2	53	199.6	17	200.6	17	26.8
1937-38	19	47	47	74.3	46	10.3	47	216.5	13	211.5	13	26.8
1938-39	22	78	77	69.1	77	10.5	77	191.4	44	215.0	44	28.3
1939-40	12	113	112	68.7	110	10.5	111	183.2	69	226.0	69	29.1
1940-41	15	103	97	71.2	97	10.7	97	201.5	51	225.7	51	29.1
1941-42	17	102	99	70.7	98	10.8	99	196.0	63	217.7	62	29.1

[1] See appendix, page 46, for description of lunar weeks. These figures give number of weeks during which at least 10 boats were fishing.

[2] Number of boats fishing chiefly or exclusively for sardines two months or more. For seasons 1932-33 through 1937-38 this was determined on the basis of boats which caught at least 8 times the average weekly catch.

[3] Number of boats for which data were available.

TABLE 11

Monterey. Length of season, fleet strength and boat characteristics

Season	Number of lunar weeks[1]	Number of boats in fleet[2]	Boat-length feet		Number of men		Horsepower of engine		Length of seine, fathoms		Depth of seine, fathoms	
			Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean
1932–33	22	30	29	60.7	28	10.0	29	119.7	28	160.1	28	33.0
1933–34	24	49	46	60.0	48	10.3	46	109.3	46	154.3	46	34.0
1934–35	27	61	51	57.1	53	10.7	51	99.0	45	146.0	45	35.0
1935–36	27	61	53	57.9	56	10.8	52	103.5	50	152.4	50	31.9
1936–37	24	62	52	61.3	58	11.3	51	117.4	53	166.4	53	32.1
1937–38	21	60	53	66.2	50	11.2	54	150.7	45	176.6	45	32.8
1938–39	25	50	43	70.2	44	11.4	43	172.4	41	192.4	41	32.1
1939–40	20	45	44	70.0	45	11.6	44	171.8	44	204.0	44	30.7
1940–41	17	77	76	71.9	76	11.4	76	200.3	63	215.3	63	32.4
1941–42	21	70	69	72.0	69	11.2	69	204.4	58	214.4	58	32.5

[1] See appendix, page 46, for description of lunar weeks. These figures give number of weeks during which at least 10 boats were fishing.
[2] Number of boats fishing chiefly or exclusively for sardines two months or more.
[3] Number of boats for which data were available.

In reckoning the number of boats fishing (Tables 10 to 12), a boat was considered fishing at a port during a season if it fished there chiefly or exclusively for sardines for at least two months. For San Francisco seasons, 1932-33 through 1937-38, data on length of time spent fishing were not readily available. To facilitate the treatment of the data for these seasons the determination of whether or not a boat was fishing was made on the basis of the amount it caught. All boats whose season's catch was at least eight times the average weekly catch, were considered fishing, thus including about the same boats as would be included under the two-month rule. Because some San Pedro boats made a habit of fishing at San Francisco before the opening of the San Pedro season, they are included in both the San Pedro and San Francisco lists for the same seasons. There was an average of only six such duplications, with a maximum of 22 in the 1941-42 season.

TABLE 12

San Pedro. Length of season, fleet strength and boat characteristics

Season	Number of lunar weeks[1]	Number of boats in fleet[2]	Boat-length feet		Number of men		Horsepower of engine		Length of seine, fathoms		Depth of seine, fathoms	
			Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean	Number[3] Boats	Mean
1932–33	21	34	33	63.1	33	10.2	33	110.1	31	203.0	32	28.3
1933–34	18	55	52	62.5	45	10.2	52	104.6	40	205.1	41	29.5
1934–35	21	76	70	62.5	75	10.4	70	106.0	67	204.0	67	28.6
1935–36	21	90	80	63.2	83	10.9	80	107.7	71	219.8	71	30.2
1936–37	17	114	106	63.3	104	10.6	106	119.6	75	217.0	73	29.7
1937–38	21	109	97	65.3	101	11.1	97	135.6	79	236.7	78	30.0
1938–39	20	102	101	65.8	98	11.1	99	145.0	79	228.3	78	29.4
1939–40	21	76	75	65.8	75	11.5	75	141.7	55	246.7	56	31.0
1940–41	19	89	86	67.2	86	11.2	86	151.3	62	237.3	62	30.4
1941–42	23	83	78	68.3	77	11.0	78	162.3	56	239.7	56	29.2

[1] See appendix, page 46, for description of lunar weeks. These figures give number of weeks during which at least 10 boats were fishing.
[2] Number of boats fishing chiefly or exclusively for sardines two months or more.
[3] Number of boats for which data were available.

Data on boats, crews, and gear were obtained from the annual boat registrations of the California Division of Fish and Game, and from the yearly lists of "Merchant Vessels of the United States," published by the United States Department of Commerce. For each port and season and for as many boats as possible, five separate data were collected, as follows: (1) length of boat in feet; (2) number of men in crew;

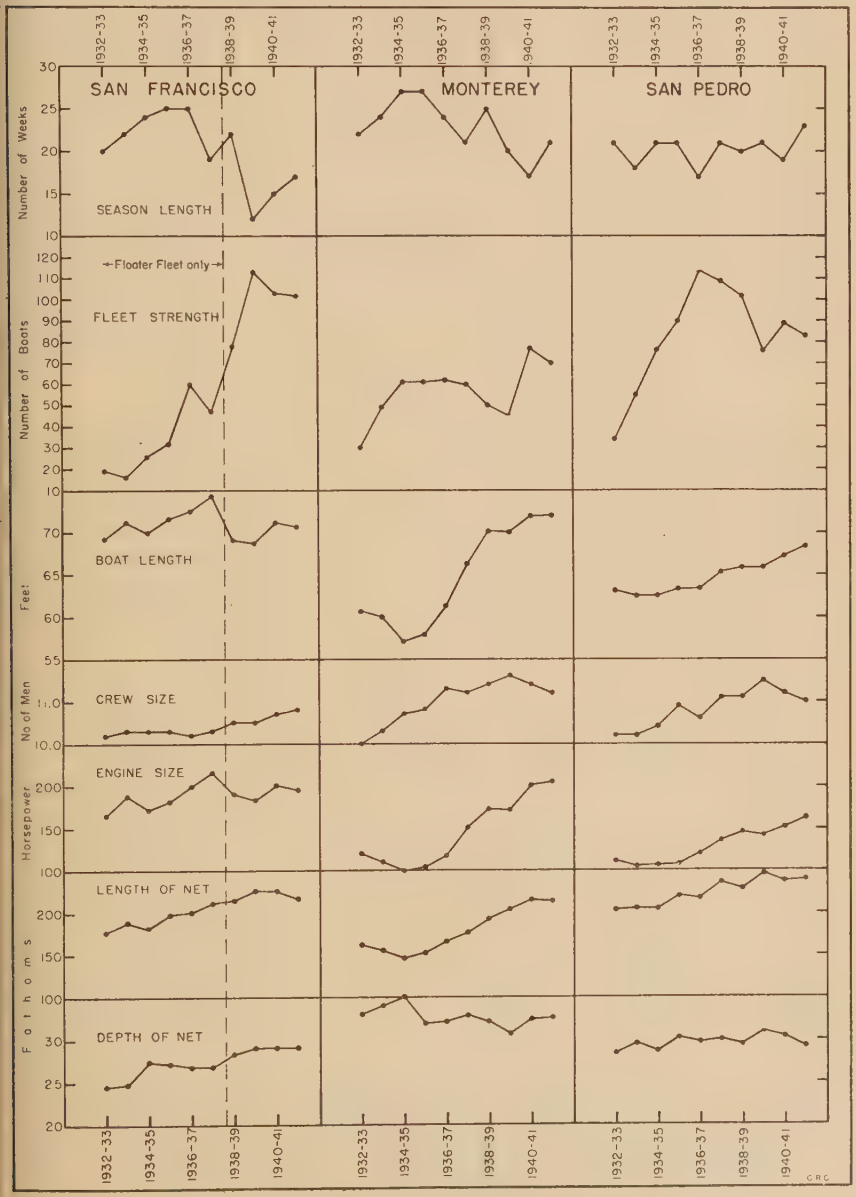

FIGURE 16. California sardine fishery; season, fleet and boat characteristics.

(3) horsepower of engine; (4) length of net in fathoms; (5) depth of net in fathoms. The numbers of boats for which each datum was available, and the means of the data, are given for each port and season in tables 10 to 12.

At San Francisco, all data for seasons, 1932-33 through 1937-38, refer only to the fleet delivering to floating reduction plants. This has been indicated in the figures by running a broken line between the 1937-38 and the 1938-39 seasons, so that curves to the left of the line refer to the floater fleet, while those to the right refer to the entire San Francisco fleet.

Effort in Terms of Fleet and Season Characteristics

Considerable experimentation was carried on with the season and fleet data, which are shown graphically in figure 16, for the purpose of obtaining a measure of total effort expended. Length of season and size of fleet were combined by taking the product of number of weeks and number of boats for each season. Of the various measures of boats and gear, length of boat and horsepower of engine proved to be most closely related to effort expended. These two measures were combined in the form:

$$\log [(\text{length} \times \text{horsepower}) - 5500].^{2}$$

This expression gives a measure which accounts for both the capacity and the speed of the boat, these two variables being measured by the length and the horsepower, respectively. The expression in its arithmetic form did not give a straight line when effort expended was plotted against it, since the increase in effort expended per unit increase in length and horsepower is not as great for large as for small boats. Taking logs, as indicated in the above expression, makes the relationship rectilinear, and thus suitable for use in conventional correlation analysis.

Since effort expended had been found to be related to both "boats times weeks" and "log [(length x horsepower)—5500]," it was desired to obtain a single equation relating the three variables. This was done by use of standard multiple correlation, and a regression equation obtained for each port. The regression coefficients and constants are as follows:

Port	Regression Coefficient for:		Added Constant
	log [(length x horsepower)—5500]	$\frac{\text{boats x weeks}}{10}$	
San Francisco	------	+0.768	+ 33.
Monterey	+0.613	+0.614	—180
San Pedro	+1.708	+0.317	—476

Equations using these coefficients and constants give estimates of effort expended in units of 10 boat weeks.[3]

[2] The figure 5500 involved in this expression was chosen arbitrarily for the purpose of securing the best fit to the logarithmic values.

[3] The unit of 10 boat weeks was used to simplify the calculations.

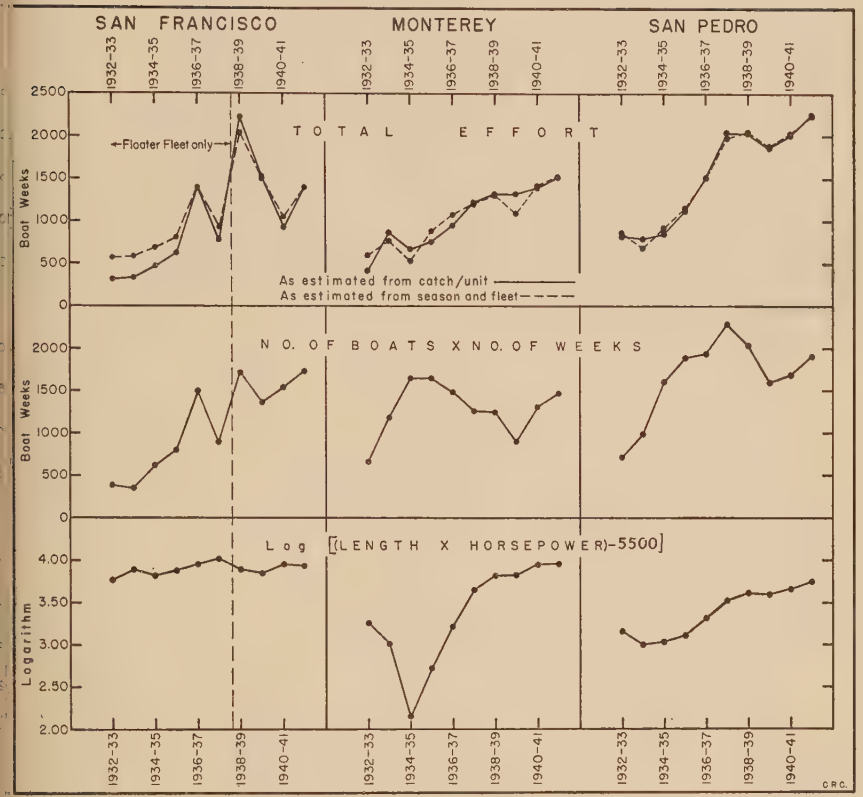

FIGURE 17. Estimation of total effort from characteristics of seasons and fleets.

TABLE 13

Total effort expended, as estimated from regression equations involving length of season, number of boats, and size of boats

Season	San Francisco[1] boat-weeks	Monterey boat-weeks	San Pedro boat-weeks
1932-33	570	600	860
1933-34	580	770	680
1934-35	680	530	920
1935-36	800	880	1,150
1936-37	1,390	1,080	1,510
1937-38	920	1,210	1,980
1938-39	2,030	1,310	2,050
1939-40	1,490	1,090	1,880
1940-41	1,030	1,420	2,030
1941-42	1,380	1,530	2,230

[1] Data for 1932-33 through 1937-38 are for floater fleet only.

Curves of the three variables involved in the equations, and a comparison of total effort as estimated from catch per-boat-week with total effort as estimated from the regression equations, are shown in figure 17. The closeness of estimate is seen to decrease as we proceed northward from San Pedro to San Francisco. For the latter port the regression equation differs from the other two in containing no coefficient for "log [(length x horsepower—5500)]." Because the larger boats (those delivering to the floating reduction plants) only were used for the seasons 1932-33 through 1937-38, the general increase in boat size as reflected at Monterey and San Pedro (Fig. 17) was obscured. This caused an extremely narrow range of boat sizes during the period of the study, not permitting a determination of the relationship between boat size and effort expended.

SUMMARY

1. The catch per-boat-week at the California sardine fishing ports of San Francisco, Monterey and San Pedro were computed, and adjusted to account for the effects of weather conditions, phase of the moon, catch limits, and varying percentages of night spent scouting.

2. For each port, adjacent weeks within seasons, and adjacent seasons within the 10-season series were related to each other by the device of comparing the performance of identical boats during these adjacent time intervals.

3. Series of weeks within seasons, and the series of 10 seasons, were linked by the "chain" method. "Fall" and "winter" parts of the seasons were also linked separately.

4. Changes in catch per-boat-week between seasons were similar for the three ports. At all of them a peak occurred in 1934-35 and a minimum in 1937-38. Comparison of the first with the last five seasons revealed decreases in level of catch in pounds per-boat-week of 47 per cent at San Francisco, 44 per cent at Monterey, and 53 per cent at San Pedro.

5. The between-season changes for fall and winter fisheries taken separately indicated that the level for the entire season at San Francisco and Monterey was largely established by the fall fishery, whereas at San Pedro the winter fishery established the entire-season level.

6. At San Francisco and Monterey a sharp change in level of catch per-boat-week between the fall and the winter fisheries was not indicated. At San Pedro the catch per-boat-week was higher in the winter than in the fall. For all ports there was some tendency for the catch per-boat-week to decrease near the end of the season.

7. The average level of catch per-boat-week was lower for southern than for central California.

8. Adjustments applied to correct for the effects of weather, phase of moon, catch limits, and percentage of available time spent scouting had relatively slight effects on the between-season trends. Their future application is not indicated unless it can be proved that they increase the accuracy of measures of catch per-boat-week and such measures are needed for extremely short time intervals.

9. The number of boat-weeks expended each season at each port was found by dividing total catch by catch per-boat-week, and a method was developed for expressing this in terms of length of season, size of fleet, and physical characteristics of boats. There was a sharp increase in the amount of effort expended per season at about the middle of the period of study, and a leveling off towards the end of the period.

APPENDIX: METHODS OF COMPUTATION

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APPENDIX: METHODS OF COMPUTATION

Source Data

Catch Records

The basic data of the catch per-unit analysis were the records of individual deliveries of sardines to the canning or reduction plants. These statistics were gathered in the course of operation of the fisheries-statistical system maintained by the Bureau of Marine Fisheries, California Division of Fish and Game. Catches are ordinarily made at night and delivered in the morning. The delivery records bear the actual calendar date of delivery, so that, for instance, a load of fish caught on the night of September 21st-22d would be dated September 22d. On relatively rare occasions the catch of a given night may be delivered before midnight of that night, in which case it would be recorded against the first of the two calendar days involved in the night, or September 21st in the example given above. In recording the catch data, deliveries of other species of fish made by boats fishing primarily for sardines were recorded as well as the sardine landings.

In addition to the records collected by the California Bureau of Marine Fisheries, part of the data for the port of San Francisco were obtained by the United States Fish and Wildlife Service, directly from the operators of floating reduction plants.

Astronomical Records

Some of the procedures described below involve the use of records of moonrise, moonset, sunrise, and sunset. These were obtained from the "Tide Tables, Pacific Ocean and Indian Ocean" published by the United States Department of Commerce, Coast and Geodetic Survey.

Weather Records

The data used in correcting for the effect of weather on the catch were deduced from barometric pressures interpolated between isobars on the daily weather maps published by the United States Weather Bureau. For the period from August, 1932, through November, 1941, the synoptic chart for 4.30 a.m. Pacific Standard Time of the day preceding the landing date was used. Because of the discontinuance of publication of this map in December, 1941, it was necessary to resort to the chart for the continental United States prepared at Washington, D. C., 1.30 a.m. Eastern Standard Time. This latter chart does not contain isobars extending out over the Pacific Ocean, so that it was necessary to extrapolate the continental isobars to obtain the required barometric pressures. All weather data subsequent to December, 1941, were obtained from such extrapolated isobars.

Interview Records

Besides the catch records mentioned above, more complete records of boat operation were secured for a portion of the deliveries to each port. These were records of interviews with the captains or other crew members of fishing boats from whose loads samples of fish were taken for measuring. Such interview records contain the following information: Date; name or number of fishing boat; name of cannery or reduction

plant to which the catch was delivered; limit, if any, imposed by the processing plant on the amount of sardines to be delivered; the amount of the catch; the time of each set of the net and the amount caught in each such set; the location of the catch; and miscellaneous remarks on weather conditions, presence of species of fish other than sardines, et cetera.

For the seasons 1932-33 to 1940-41 at Monterey and 1932-33 to 1938-39 at San Pedro, 10 interviews per week were recorded. At San Pedro in 1939-40 and 1940-41 about 20 interviews per week were obtained. In 1941-42 daily records of approximately one interview for each 10 loads of fish were secured at Monterey and San Pedro. Interviewing was more irregular at San Francisco, around 150-200 per season being recorded from 1935-36 to 1940-41. In the 1941-42 season the San Francisco interviews were placed on the basis of one to each five deliveries.

Organization of Data

Selection of the Fleet

The present study is based in part on the study of Sette and Palmer (unpublished ms), involving boats delivering to floating reduction plants off San Francisco during the seasons 1931-32 through 1937-38. For those San Francisco seasons boats to be included in the study were selected from the fleet of 35 boats used by Sette and Palmer. The method of selection of this fleet is described in the following quotation from their manuscript:

> "* * * a preliminary selection was made of those boats that had fished at least three consecutive seasons, and had delivered at at least 1,000 tons to the high-seas reduction ships in one of those seasons. In addition to these, three boats were selected which had fished only two consecutive seasons, and one boat which had delivered on the high seas every other season for three out of five years. For these boats, the addition of their deliveries to shore plants served to complete their records sufficiently to make them conform to the 47 selected under the stated criterion."
>
> "Among the total of 51 boats there were some which had identical, or nearly identical, names, and since their individual landings would be of uncertain identity, eight pairs, or 16 boats, were dropped, leaving 35 boats in the final list."

For all other ports and seasons the fleets were selected from the records of the Bureau of Marine Fisheries of the California Division of Fish and Game. This organization compiles the monthly landings by regions of each boat fishing out of California ports, and the boats to be used in the study were selected on the basis of tables of these landings.

For each of the three regions, San Francisco, Monterey and San Pedro, a list was compiled of boats which fished sardines exclusively or chiefly for two or more months of any given season. No boat was included in the list whose monthly landings did not consist of at least 50 per cent sardines. The numbers of boats available each season and the percentages of the total catches which they landed are given in table 14. The low percentages for San Francisco 1932-33 through 1937-38 result from the use only of boats delivering to floating reduction plants.

TABLE 14

Number of boats available for boat-catch analysis and percentage of the total catch landed by these boats

Season	Region					
	San Francisco		Monterey		San Pedro	
	Number	Per cent	Number	Per cent	Number	Per cent
1932–33	23	79	30	78	34	71
1933–34	28	84	49	73	55	84
1934–35	35	74	61	72	76	88
1935–36	33	54	61	84	90	90
1936–37	32	30	62	88	114	81
1937–38	34	22	60	88	109	76
1938–39	78	70	50	91	102	80
1939–40	113	62	45	65	76	73
1940–41	103	92	77	86	89	76
1941–42	102	88	70	90	83	77

The Lunar-Month Calendar

Since there is practically no fishing at the time of full moon, the lunar month, or period between full moon dates, forms a natural time unit for recording the catch, and all catch data were compiled in accordance with a standardized calendar divided into lunar months and lunar quarters. The lunar months are numbered consecutively, starting with lunar month one, which covered the period November 7th to December 7th, 1919. This date marks the beginning of the sardine studies by the California Division of Fish and Game.

Lunar quarters were determined with reference to what was known as the zero lunar day. This was the day in each lunar month following the night having the longest period during which neither the sun nor the moon was up. This usually coincided with the calendar date of new moon, and never varied more than one day from it. In cases where two nights had an equal "period of darkness" the date chosen was the fifteenth day in a 29-day month and the sixteenth day in a 30-day month (where the months run from the day following the full moon to the succeeding full moon).

Third lunar quarter included the zero date and the six following days. The second quarter included the seven days immediately preceding the zero date. The fourth quarter consisted of the eight days following the third quarter. The number of days in the first quarter depended on the number of days between the preceding and succeeding zero dates. Where there were 30 days between zero dates, the first quarter included the eight days preceding the second quarter, and where there were 29 days between zero dates, the first quarter included the seven days preceding the second quarter. A schedule of lunar weeks for the seasons covered in the analysis is given in table 15. Lunar weeks were assigned numerical designations consisting of a digit showing their position in the lunar month. Thus the four weeks of lunar month 185 are 185-1, 185-2, 185-3 and 185-4.

TABLE 15

Schedule of lunar months and lunar weeks as used in the catch-per-unit analysis. First and last dates of the four lunar weeks in each lunar month are given

Lunar month designation	Fishing Season																														
	1932–1933			1933–1934			1934–1935			1935–1936			1936–1937			1937–1938			1938–1939			1939–1940			1940–1941			1941–1942		
	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To	L.W. No.	From	To
July	158–1			170–1			182–1			195–1			207–1			219–1			232–1			244–1			257–1			269–1		
	158–2		Aug. 1	170–2			182–2			195–2			207–2			219–2			232–2			244–2			257–2	Aug. 1	Aug. 2	269 2		
	158–3	Aug. 2	8	170–3			182–3			195–3	Aug. 1	Aug. 6	207–3			219–3			232–3	Aug. 1	Aug. 2	244–3			257–3	3	9	269–3		
	158–4	9	16	170–4	Aug. 1	Aug. 5	182–4			195–4	7	13	207–4		Aug. 1	219–4			232–4	3	10	244–4			257–4	10	17	269–4	Aug. 1	Aug. 7
August	159–1	17	23	171–1	6	13	183–1	Aug. 1	Aug. 2	196–1	14	21	208–1	Aug. 2	9	220–1			233–1	11	17	245–1	Aug. 1	Aug. 7	258–1	18	25	270 1	8	14
	159–2	24	30	171–2	14	20	183–2	3	9	196–2	22	28	208–2	10	16	220–2	Aug. 1	Aug. 5	233–2	18	24	245–2	8	14	258–2	26	Sept. 1	270 2	15	21
	159–3	31	Sept. 6	171–3	21	27	183–3	10	16	196–3	29	Sept. 4	208–3	17	23	220–3	6	12	233–3	25	31	245–3	15	21	258–3	Sept. 2	8	270–3	22	28
	159–4	Sept. 7	14	171–4	28	Sept. 4	183–4	17	24	196–4	Sept. 5	12	208–4	24	31	220–4	13	20	233–4	Sept. 1	Sept. 8	245–4	22	29	258–4	9	16	270 4	29	Sept. 5
September	160–1	15	22	172–1	Sept. 5	11	184–1	25	Sept. 1	197–1	13	19	209–1	Sept. 1	Sept. 7	221–1	21	28	234–1	9	16	246–1	30	Sept. 5	259–1	17	24	271–1	Sept. 6	13
	160–2	23	29	172–2	12	18	184–2	Sept. 2	8	197–2	20	26	209–2	8	14	221–2	29	Sept. 4	234–2	17	23	246–2	Sept. 6	12	259–2	25	Oct. 1	271–2	14	20
	160–3	30	Oct. 6	172–3	19	25	184–3	9	15	197–3	27	Oct. 3	209–3	15	21	221–3	Sept. 5	11	234–3	24	30	246–3	13	19	259–3	Oct. 2	8	271–3	21	27
	160–4	Oct. 7	14	172–4	26	Oct. 3	184–4	16	23	197–4	Oct. 4	11	209–4	22	29	221–4	12	19	234–4	Oct. 1	Oct. 8	246–4	20	27	259–4	9	16	271–4	28	Oct. 5
October	161–1	15	22	173–1	Oct. 4	11	185–1	24	30	198–1	12	19	210–1	30	Oct. 7	222–1	20	26	235–1	9	15	247–1	28	Oct. 4	260–1	17	23	272 1	Oct. 6	12
	161–2	23	29	173–2	12	18	185–2	Oct. 1	Oct. 7	198–2	20	26	210–2	Oct. 8	14	222–2	27	Oct. 3	235–2	16	22	247–2	Oct. 5	11	260–2	24	30	272–2	13	19
	161–3	30	Nov. 5	173–3	19	25	185–3	8	14	198–3	27	Nov. 2	210–3	15	21	222–3	Oct. 4	10	235–3	23	29	247–3	12	18	260–3	31	Nov. 6	272–3	20	26
	161–4	Nov. 6	13	173–4	26	Nov. 2	185–4	15	22	198–4	Nov. 3	10	210–4	22	29	222–4	11	18	235–4	30	Nov. 6	247–4	19	26	260–4	Nov. 7	14	272–4	27	Nov. 3
November	162–1	14	20	174–1	Nov. 3	9	186–1	23	30	199–1	11	18	211–1	30	Nov. 6	223–1	19	26	236–1	Nov. 7	14	248–1	27	Nov. 3	261–1	15	21	273–1	Nov. 4	11
	162–2	21	27	174–2	10	16	186–2	31	Nov. 6	199–2	19	25	211–2	Nov. 7	13	223–2	27	Nov. 2	236–2	15	21	248–2	Nov. 4	10	261–2	22	28	273–2	12	18
	162–3	28	Dec. 4	174–3	17	23	186–3	Nov. 7	13	199–3	26	Dec. 2	211–3	14	20	223–3	Nov. 3	9	236–3	22	28	248–3	11	17	261–3	29	Dec. 5	273–3	19	25
	162–4	Dec. 5	12	174–4	24	Dec. 1	186–4	14	21	199–4	Dec. 3	10	211–4	21	28	223–4	10	17	236–4	29	Dec. 6	248–4	18	25	261–4	Dec. 6	13	273 4	26	Dec. 3
December	163–1	13	19	175–1	Dec. 2	9	187–1	22	28	200–1	11	17	212–1	29	Dec. 5	224–1	18	24	237–1	Dec. 7	14	249–1	26	Dec. 3	262–1	14	20	274–1	Dec. 4	10
	163–2	20	26	175–2	10	16	187–2	29	Dec. 5	200–2	18	24	212–2	Dec. 6	12	224–2	25	Dec. 1	237–2	15	21	249–2	Dec. 4	10	262–2	21	27	274 2	11	17
	163–3	27	Jan. 2	175–3	17	23	187–3	Dec. 6	12	200–3	25	31	212–3	13	19	224–3	Dec. 2	8	237–3	22	28	249–3	11	17	262–3	28	Jan. 3	274–3	18	24
	163–4	Jan. 3	10	175–4	24	31	187–4	13	20	200–4	Jan. 1	Jan. 8	212–4	20	27	224–4	9	16	237–4	29	Jan. 5	249–4	18	25	262–4	Jan. 4	11	274–4	25	Jan. 1
January	164–1	11	17	176–1	Jan. 1	Jan. 7	188–1	21	28	201–1	9	16	213–1	28	Jan. 4	225–1	17	24	238–1	Jan. 6	12	250–1	26	Jan. 1	263–1	12	19	275–1	Jan. 2	9
	164–2	18	24	176–2	8	14	188–2	29	Jan. 4	201–2	17	23	213–2	Jan. 5	11	225–2	25	31	238–2	13	19	250–2	Jan. 2	8	263–2	20	26	275 2	10	16
	164–3	25	31	176–3	15	21	188–3	Jan. 5	11	201–3	24	30	213–3	12	18	225–3	Jan. 1	Jan. 7	238–3	20	26	250–3	9	15	263–3	27	Feb. 2	275–3	17	23
	164–4	Feb. 1	Feb. 8	176–4	22	29	188–4	12	19	201–4	31	Feb. 7	213–4	19	26	225–4	8	15	238–4	27	Feb. 3	250–4	16	23	263–4	Feb. 3	10	274–4	24	31
February	165–1	9	16	177–1	30	Feb. 6	189–1	20	26	202–1	Feb. 8	14	214–1	27	Feb. 3	226–1	16	23	239–1	Feb. 4	11	251–1	24	31	264–1	11	18	276–1	Feb. 1	Feb. 7
	165–2	17	23	177–2	Feb. 7	13	189–2	27	Feb. 2	202–2	15	21	214–2	Feb. 4	10	226–2	24	30	239–2	12	18	251–2	Feb. 1	Feb. 7	264–2	19	25	276–2	8	14
	165–3	24	Mar. 2	177–3	14	20	189–3	Feb. 3	9	202–3	22	28	214–3	11	17	226–3	31	Feb. 6	239–3	19	25	251–3	8	14	264–3	26	Mar. 4	276–3	15	21
	165–4	Mar. 3	10	177–4	21	28	189–4	10	17	202–4	29	Mar. 7	214–4	18	25	226–4	Feb. 7	14	239–4	26	Mar. 5	251–4	15	23	264–4	Mar. 5	12	276–4	22	Mar. 1
March	166–1	11	18	178–1	Mar. 1	Mar. 7	190–1	18	25	203–1	Mar. 8	14	215–1	26	Mar. 5	227–1	15	22	240–1	Mar. 6	13	252–1	23	Mar. 1	265–1	13	20	277–1	Mar. 2	9
	166–2	19	25	178–2	8	14	190–2	26	Mar. 4	203–2	15	21	215–2	Mar. 6	12	227–2	23	Mar. 1	240–2	14	20	252–2	Mar. 2	8	265–2	21	27	277 2	10	16
	166–3	26	April 1	178–3	15	21	190–3	Mar. 5	11	203–3	22	28	215–3	13	19	227–3	Mar. 2	8	240–3	21	27	252–3	9	15	265–3	28	April 3	277–3	17	23
	166–4			178–4	22	29	190–4	12	19	203–4	29	April 5	215–4	20	27	227–4	9	16	240–4	28	April 4	252–4	16	23	265–4			277–4	24	31
April	167–1			179–1	30	April 5	191–1	20	26				216–1	28	April 3	228–1	17	23				253–1	24	31						
	167–2			179–2			191–2	27	April 2				216–2	April 4	10	228–2	24	30				253–2	April 1	April 7						
	167–3			179–3			191–3	April 3					216–3	11		228–3	31	April 6												
	167–4			179–4			191 4						216–4			228–4														

Calculation of Percentage of Available Time Spent Scouting

Available Scouting Time

The amount of time available to the interviewed boats for scouting was estimated from the times of rising and setting of the sun and moon, supplemented by certain empirical data on the habits of the fishermen.

In determining the beginning and end of the scouting period, the first step was to record, for each night on which one or more boats furnishing interviews made a catch, the time of moonset and moonrise and of sunset and sunrise. As a basing point for studying the beginning of scouting time, sunset or moonset, whichever occurred last, was used. Likewise, sunrise or moonrise, whichever occurred first, was used as a basing point for determining the end of the available scouting period.

Using the two time data just mentioned for each night, the recorded time of each haul made by all of the boats from which interviews were obtained, was tabulated in relation to the nearest datum. In making this tabulation, the days of each lunar month were numbered serially starting with zero for the zero date (as described above) and proceeding either way toward the beginning and end of the month. Those days occurring before the zero date were distinguished by prefixing a minus sign to their serial number. Thus the sequence of lunar days in a 29-day lunar month would be as follows: —14, —13 . . . —2, —1, 0, 1, 2 . . . 13, 14. The tabulation of time of haul lumped, for the series of seasons covered, all of the days which had like number and sign. Because of the regular nature of the movements of the sun and moon, the minus lunar

TABLE 16

Distribution of haul times in relation to sunset and moonrise, San Pedro, fishing seasons 1932-33 to 1937-38

	Time from nearest astronomical event, hours	Lunar day number: −8		−7		−6		−5		−4	
		Number of hauls nearest to sunset	Number of hauls nearest to moonrise	Number of hauls nearest to sunset	Number of hauls nearest to moonrise	Number of hauls nearest to sunset	Number of hauls nearest to moonrise	Number of hauls nearest to sunset	Number of hauls nearest to moonrise	Number of hauls nearest to sunset	Number of hauls nearest to moonrise
BEFORE	5.0										3
	4.5						2		6		2
	4.0				1		2		2		5
	3.5				4		3		3		1
	3.0		3		2		3				3
	2.5		3		2		2		1		2
	2.0		3		2		6		1		
	1.5		7		3		3				
	1.0		5		1		8		1		
	.5		3		3				3		
	.0		1		1		6				
	.5		3		3		1	1	1		
AFTER	1.0			1	1	1	2	1		1	
	1.5	3		1		4	1	2		2	
	2.0	4		2		10	4	1	1	1	
	2.5	1		4	2	6		3		2	
	3.0	3		1	1	4	1	4		9	
	3.5			3		6	1	2		1	
	4.0			1		1	1	7		1	
	4.5					2		1		2	
	5.0									2	

days always had their nights beginning with sunset and ending with moonrise and the plus days beginning with moonset and ending with sunrise. For each lunar day the tabulation showed the time before or after the nearest astronomical event when each haul occurred. A portion of one of the tabulations is shown in table 16, as an example. Similar tabulations covering the entire lunar month were prepared for San Pedro, fishing seasons 1932-33 to 1937-38, Monterey 1932-33 to 1937-38 and San Francisco 1935-36 to 1941-42.

Study of these tabulations provided the basis for a series of rules which could be used in estimating the time of beginning and end of the scouting period for each individual day. These rules, and the reasons for adopting them, follow.

Rule 1. Scouting begins at sunset for lunar days —9 to —15.

Reason: The haul tabulations showed that boats actually did make sets shortly after sunset in this portion of the lunar month when there was only a short time interval between sunset and moonrise.

Rule 2. Scouting begins one hour after sunset for lunar days 0 to —8, except for nights covered by Rule 3.

Reason: The tabulations showed only occasional instances where catches were made within an hour after sunset, and it appears quite likely that during this portion of the lunar month when the period of darkness was long the fishermen did not regularly attempt to do any scouting during the evening twilight.

Rule 3. On nights when catches are made within the hour after sunset scouting begins at the time of the earliest catch within that hour.

Reason: This is to take care of exceptional cases where Rule 2 would ignore early catches and it assumes that if one boat has made such a catch, other boats also availed themselves of that opportunity.

Rule 4. Scouting stops at moonrise for lunar days —1 to —15, except on nights when catches are made after moonrise.

Reason: The tabulations showed that on by far the majority of nights no catches were made after moonrise. Therefore it was assumed that scouting usually ended with the rise of the moon.

Rule 5. On nights when catches are made after moonrise but not more than two hours thereafter, scouting stops at the time of the last catch.

Reason: There were a number of instances when sets were recorded as having taken place after moonrise. Presumably these were instances when the schooling habits of the fish or overcast skies favored the catching of fish even after moonrise. This rule assumes that where any interview boat has made a catch under these circumstances the other boats had an equal opportunity to do so.

Rule 6. On nights when catches are made later than two hours after moonrise scouting stops two hours after moonrise, except for catches made later than this. For the latter, scouting time stops at the time of the catch.

Reason: There were a few instances when sets were recorded in the interviews as having been made a long time after moonrise. It did not

eem appropriate to assume that the entire fleet scouted for such a long eriod after moonrise, so a compromise measure of allowing an additional wo hours of scouting time for the other boats was adopted.

Rule 7. Scouting time starts at moonset for lunar days +1 to +15, xcept on nights when catches are made earlier.

Reason: The numerous instances of catches within a half hour of noonset indicated that scouting must usually have begun promptly at moonset.

Rule 8. On nights when catches are made before moonset but not nore than two hours before moonset, scouting starts at the time of the arliest catch.

Reason: Similar to that for Rule 3.

Rule 9. On nights when catches are made earlier than two hours efore moonset, scouting starts two hours before moonset except for the atches made earlier than this. For the latter, scouting starts at the ime of the catch.

Reason: Similar to that for Rule 6.

Rule 10. Scouting stops at sunrise for lunar days +9 to +15.

Reason: Similar to that for Rule 1.

Rule 11. Scouting stops one hour before sunrise for lunar days) to +8 except when catches are made within the hour before sunrise.

Reason: Similar to Rule 2.

Rule 12. On nights when catches are made within the hour before unrise, scouting time stops at the time of the latest catch within that nour.

Reason: Similar to that for Rule 3.

Time Spent in Catching Operations

To determine the actual amount of time spent scouting, it was necssary to deduct from the scouting interval as determined above the mount of time spent in setting and hauling the net, and in brailing the sh into the hold of the boat. Some observational data which had been athered aboard fishing boats indicated an allowance of one hour for andling the net plus one minute per ton of fish caught. This allowance as tested by correlating the time between pairs of hauls with the amount f fish caught in the first haul of each pair. The correlation indicated hat the stated allowance did not exceed the time available between hauls n the great majority of instances. The instances in which it did exceed he available time could be explained by the rather rough nature of the ime records as reported in the interviews. Therefore the allowance as tated was used in the computations.

Termination of Scouting

Scouting was assumed to have ended before the ending of the avail- ble scouting period if the catch in question was affected by either limits mposed by the processing plants or limits imposed by the fishermen themselves.

For boats upon which catch limits had been imposed by the process- ng plants, it was assumed that scouting ended at the time of the last

haul if the delivered catch was within 10 tons of the limit stated in the interview. This assumption was based on the belief from inspection of the interview records that on the average boats did not continue to fish when there were less than ten tons remaining to be caught under the limit, and that on the average a tolerance of ten tons over the limit was practiced.

A study of the amounts of fish aboard boats before and after the last haul in multiple-haul catches showed that fishermen did not frequently make another set after having caught 60 tons of fish, even though their boats were physically able to bring in much more. This held true, in so far as could be determined, for all purse seine boats. For the lampara or small ring net boats a 30-ton figure was found to be most appropriate. Thus, in computing the amount of time spent scouting it was assumed that scouting terminated when the catch of a lampara or ring net boat reached 30 tons, or of a purse seine boat 60 tons.

Special Instances

Because it was not always possible to get complete interview data from each boat interviewed, and because of certain other special circumstances, there were some landings which did not fit into the above schedule for computing scouting time. Arbitrary treatment of these instances was necessary, and to secure uniformity certain rules were laid down to cover them. These rules are as follows:

Rule 1. Where the tonnage for individual hauls of multiple-haul trips is not given, assume that equal tonnage was caught each haul.

Rule 2. Where the time of individual hauls is not given, but scouting is assumed to have continued until the end of the available scouting period, assume that the setting and brailing for the last haul was completed before the end of the available scouting period.

Rule 3. Exclude any catches before sunset or after sunrise. (These catches were omitted because they obviously represent a different type of fishing condition from the usual night hauls. There were very few of them).

Rule 4. When the limit is not stated in the interview, it shall be considered to be the mean limit to the nearest five tons of those limits given in the interviews for the given date and the first preceding and first subsequent sampling days within the lunar period.

All of these rules refer to occurrences which were relatively rare. Moreover, they usually affected only one step in the calculations, so that their aggregate effect on the results was small.

Procedure

Scouting time was computed in units of one lunar week, as defined in the section on "*The Lunar-Month Calendar.*" Such a lunar quarter would have within it one or two days on each of which five interviews were obtained, making five or 10 interviews for the lunar week. Each haul of each catch was recorded on a separate line of the work-sheets used.

First the amount of available scouting time was determined. This was obtained by subtracting the time the scouting period began from the time it ended, such times being determined as described in the section

n *"Available Scouting Time."* These periods were summed for all the nterviews obtained during the week, giving the total amount of available scouting time for the week.

The amount of time actually spent scouting by each interviewed oat was determined next. In making this determination it was assumed hat the times of hauls given in interviews were the times the hauls began. he times of ending of the hauls were determined by adding the time or handling the net and brailing in the fish to the time the haul began, he netting and brailing times being determined as described in the ection *"Time Spent in Catching Operations."* Scouting was assumed o have begun at the beginning of the available scouting period, and to ave ended at the end of that period, unless terminated earlier as described under *"Termination of Scouting."* The data thus recorded ave a chronological record of the operation of each interviewed boat for he fishing nights covered by the interviews. The intervals between eginning and end of scouting not taken up by catching operations were dded to obtain the total scouting time spent for each catch. These totals ere summed for the lunar week to give the grand total time spent scouting.

TABLE 17

unar weekly average percentage of available time spent scouting, San Francisco, for each fishing season.

1935-36		1936-37		1937-38		1938-39		1939-40		1940-41		1941-42	
Lunar week number	Per cent	Lunar week number	Per cent	Lunar week number	Per cent	Lunar week number	Per cent	Lunar week number	Per cent	Lunar week number	Per cent	Lunar week number	Per cent
197-1	69.2	209-3	86.9	220-4	58.7	233-2	80.3	247-2	62.1	258-4	50.5	270-1	67.0
-2	47.5	-4				-3	83.9	-3	72.0			-2	71.9
-3	58.5			221-1	66.7	-4	46.7	-4	53.3	259-1	86.4	-3	60.0
-4	36.8	210-1		-2	65.4					-2	74.8	-4	57.7
198-1	61.9	-2	86.4	-3	82.2	234-1	75.3	248-1	87.5	-3	75.3		
-2	73.3	-3	77.3	-4	66.0	-2	65.1	-2	65.1	-4	58.9	271-1	85.7
-3	27.0	-4				-3	81.4	-3	76.3			-2	70.3
-4	43.8			222-1	78.7	-4	67.9	-4	76.0	260-1	71.3	-3	64.1
		211-1		-2	68.0					-2	78.1	-4	80.3
199-1	77.8	-2	58.6	-3	71.4	235-1	68.3	249-1	63.6	-3	70.2		
-2	44.5	-3	79.5	-4	57.4	-2	77.5	-2	59.5	-4	44.8	272-1	96.4
-3	19.3	-4	73.2			-3	69.5	-3	65.4			-2	74.4
-4	42.9			223-1	80.0	-4	46.2	-4	74.6	261-1	70.9	-3	52.0
		212-1	68.5	-2	80.9					-2	71.0	-4	11.8
200-1	71.7	-2	84.7	-3	87.6	236-1		250-1		-3	56.3		
-2		-3	63.9	-4	66.0	-2	64.9	-2		-4	56.1	273-1	73.7
-3	43.5	-4	50.0			-3	65.4	-3	77.3			-2	68.8
-4				224-1	78.8	-4		-4	83.3	262-1		-3	58.5
		213-1		-2	67.1					-2		-4	75.0
201-1		-2	80.7	-3	78.6	237-1	80.0	251-1	69.6	-3	81.2		
-2	45.8	-3	64.2	-4	65.6	-2		-2	67.0	-4	80.0		
-3	61.7	-4	57.1			-3	42.7	-3	83.5				
				225-1	89.2	-4				263-1	72.9		
		214-1		-2	74.5					-2	47.4		
		-2	73.5	-3	71.9	238-1	75.4			-3	69.4		
				-4	75.6	-2	71.9			-4	79.1		
						-3	70.5						
				226-1	71.4								
				-2	62.4								

TABLE 18

Lunar weekly average percentage of available time spent scouting, Monterey, for each fishing season

1932-33		1933-34		1934-35		1935-36		1936-37		1937-38		1938-39		1939-40		1940-41		1941-42	
Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent
159-1	75.5	171 1	76.0	183-2	73.7	195-3	76.1	208-2	83.1	220-3	88.0	232-4	85.3	246-3	63.2	259-3	27.1	270-1	95.6
-2	74.5	-2	68.2	-3	38.7	-4	72.7	-3	61.1	-4	63.8			-4	61.9	-4	46.9	-2	73.0
-3	71.6	-3	47.2	-4	41.9			-4	48.4			233-1	87.5					-3	74.2
-4	45.0	-4	53.6			196-1				221-1	86.2	-2	59.3	247-1	76.0	260 1	78.7	-4	68.1
				184 1	44.2	-2	71.8	209-1	64.3	-2	66.6	-3	80.6	-2	72.5	-2	56.7		
160-1	85.3	172-1	47.6	2	48.5	-3	57.7	-2	77.9	-3	73.6	-4	54.4	-3	39.5	3	83.7	271 1	78.7
-2	72.7	-2	73.8	-3	61.6	-4	35.6	-3	56.7	-4	58.5			-4	57.0	-4	51.3	-2	79.2
-3	35.2	-3		-4	41.8			-4	50.4			234-1	80.9					-3	52.0
-4	56.3	-4				197-1	71.8			222-1	70.0	-2	81.4	248-1	85.5	261-1		-4	60.4
				185-1	76.0	-2	51.1	210-1	77.1	-2	73.0	-3	53.7	-2	53.6	-2	72.0		
161-1	73.2	173-1		-2	55.5	-3	46.6	-2	56.0	-3	42.4	-4	39.3	-3	55.6	-3	33.9	272-1	95.4
-2	58.8	-2	58.6	-3	30.9	-4	41.5	-3	60.4	-4	54.2			-4	55.8	4	27.6	2	76.7
-3	54.0	-3	54.2	-4	52.7			-4	66.1			235-1	67.2					-3	39.7
-4	70.8	-4	41.0			198-1	65.9			223-1	68.1	2	69.7	249-1	84.4	262-1		-4	55.7
				186-1	83.5	-2	54.1	211-1	77.4	2	63.4	-3	60.0	2	66.5	-2			
162-1	85.7	174-1	63.3	-2	70.0	-3	68.8	-2	39.8	-3	54.1	-4	68.8	-3	55.9	-3	61.2	273-1	68.5
-2	64.0	-2	53.1	-3	59.4	-4	34.6	-3	61.4	-4	75.0			-4	44.9	-4	58.3	-2	67.4
-3	42.0	-3	62.8	-4				-4	25.0			236-1	82.7					-3	53.6
-4	55.0	-4	55.0			199-1	62.5			224-1		2	61.9	250-1		263 1	66.7	-4	35.8
				187-1	73.3	2	49.0	212-1	78.0	-2	78.2	3	65.4	2	70.2	-2	78.5		
163-1	76.0	175-1	67.3	-2	51.1	-3	29.2	-2	63.1	-3	49.6	-4	75.0	-3	62.1	-3	75.1	274 1	
-2	71.5	-2	78.4	-3	45.3	-4	41.6	-3	77.8	4	76.0			-4	34.4	4	72.9	-2	
-3	42.5	-3	46.8	-4	37.0			-4	56.2			237-1	66.1					3	61.0
-4	41.8	-4				200-1	76.0			225-1	62.6	-2	54.0	251-1	87.1	264-1	66.7	-4	
				188-1	89.5	-2	51.0	213-1	78.6	-2	67.3	-3	63.3	-2	27.6				
164-1	66.6	176-1	80.0	-2	36.5	-3	66.3	-2	69.3	-3	63.6	-4	49.2	-3	63.4			275-1	75.7
-2	48.7	-2	58.0	-3	47.2	-4	57.1	-3	67.3	-4	69.4							-2	76.6
-3	35.9	-3	66.5	-4				-4				238 1	88.3					3	75.6
-4	20.0	-4	52.7			201-1	60.0			226-1	89.7	-2	61.3					-4	
				189-1	65.2	-2	53.9	214-1	69.4	-2	70.5	-3	53.2						
165-1	46.3	177-1	85.1	-2	67.1	-3	39.7	-2	55.2	-3								276-1	
		-2	24.8	-3	64.0	-4		-3	70.7	-4	73.8							-2	53.2
		-3	80.9	-4	49.3													-3	75.4
						202-1	62.3												

TABLE 19

Lunar weekly average percentage of available time spent scouting, San Pedro, for each fishing season

1932-33		1933-34		1934-35		1935-36		1936-37		1937-38		1938-39		1939-40		1940-41		1941-42	
Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent	Lunar week No.	Per cent
161-3	60.1	174-1	75.0	186-2	78.2	198-3	61.9	212-2	84.5	223-2	87.5	235-4	63.3	248-1	78.0	260-3	54.0	271-4	52.5
-4	64.0	-2	80.5	-3	69.0	-4	55.0	-3	66.1	-3	70.7			-2	73.5	-4	50.0		
		-3	71.4	-4	18.1			-4	55.8	-4	74.5	236-1	70.0	-3	69.1			272-1	74.4
162-1	100.0	-4	65.0			199-1	76.8					-2	59.1	-4	70.8	261-1	88.1	-2	48.1
-2	52.7			187-1	62.5	-2	29.5	213-1	86.1	224-1	75.0	-3	63.0			-2	74.4	-3	58.7
-3	67.3	175-1	81.9	-2	69.8	-3	54.0	-2	78.9	-2	67.9	-4	62.0	249-1	65.6	-3	56.8	-4	67.7
-4	48.3	-2	61.2	-3	62.5	-4	62.5	-3	73.6	-3	63.6			-2	67.4	-4	63.1		
		-3	55.0	-4	59.4			-4	63.6	-4	50.0	237-1	52.2	-3	72.1			273-1	84.5
163-1	48.8	-4	73.4			200-1	56.6					-2	53.9	-4	71.4	262-1	70.7	-2	71.2
-2	34.1			188-1	38.1	-2	70.5	214-1	72.2	225-1	83.6	-3	54.3			-2	61.2	-3	78.2
-3	76.4	176-1	81.8	-2	55.9	-3	81.3	-2	77.6	-2	68.2	-4	59.8	250-1		-3	74.5	-4	72.0
-4	66.9	-2	61.4	-3	52.1	-4	70.6	-3	55.6	-3	85.0			-2	67.3	-4	65.6		
		-3	53.2	-4	32.0			-4	46.1	-4	56.6	238-1		-3	72.1			274-1	58.3
164-1	95.0	-4	42.8			201-1	62.9					-2	52.2	-4	62.2	263-1	66.7	-2	66.0
-2	72.6			189-1	38.1	-2	66.9	215-1	57.8	226-1	89.5	-3	69.8			-2	65.3	-3	72.0
-3	58.1	177-1	65.8	-2	49.0	-3	53.1	-2	61.1	-2	60.9	-4	67.6	251-1	65.2	-3	74.6	-4	
-4	52.2	-2	47.5	-3	39.0	-4	53.3	-3	69.8	-3	77.0			-2	78.8	-4	71.9		
		-3	44.8	-4	40.0			-4	81.2	-4	67.1	239-1	67.7	-3	61.5			275-1	80.0
165-1	69.0	-4	9.3			202-1						-2	74.7	-4	66.7	264-1	62.0	-2	78.2
-2	74.3			190-1	60.0	-2	66.0	216-1	82.6	227-1	73.2	-3	58.8			-2	61.0	-3	67.0
-3	48.1	178-1	79.8	-2	29.6	-3	67.8			-2	71.2	-4	60.0	252-1	70.3	-3	71.7	-4	62.6
-4	32.5	-2	35.5	-3	55.5	-4	47.1			-3	79.0			-2	73.0	-4	72.1		
		-3	43.5	-4	76.2					-4	73.3	240-1	64.4	-3	73.6			276-1	68.6
166-1	68.7					203-1	80.5					-2	71.4	-4	42.8	265-1	68.8	-2	68.8
-2	70.5			191-1	66.6	-2	39.3			228-1	80.0	-3	71.6			-2		-3	79.0
-3	76.5			-2	74.2	-3	71.3			-2	92.2	-4	54.8	253-1	76.8	-3	85.0	-4	61.1
						-4	63.3			-3	76.4								
																		277-1	86.7
																		-2	73.3
																		-3	89.0

Having estimated the total time available for scouting and the total time spent scouting, the percentage of available time used for scouting was calculated for each week. The percentage values for each lunar week of the seasons in the analysis are given in tables 17, 18, and 19. In some instances the value for the week is missing, indicating that no interviews were obtained during that week. In subsequent computations these hiatuses were filled by assuming that the value for the week with the datum missing was the same as the value for the nearest comparable lunar week. The comparable week was determined by the amount of scouting time available per night. In general the available scouting time was at a maximum at the center of the lunar period, decreasing more or less symmetrically toward the ends of the month. Thus lunar weeks 1 and 4, and 2 and 3, had roughly comparable amounts of available time.

Calculation of Average Catch per-Boat-per-Night

Determination of Number of Boats Fishing

Since records of boat operation were lacking, it was necessary to estimate in some way the number of boats fishing each night. It was of course known which boats made landings, but there were no records for those which fished and did not catch anything. The estimation of number of boats fishing was made in units of one lunar week. A rule was made, based on inspection of the data, that a boat would be counted as fishing in a given lunar week, even though it made no landings in that week, if it made a landing in both the previous and subsequent lunar weeks and if at least one-third of the boats fishing in the week under question made only one landing each. An example of the application of this rule is given in table 20, where weeks in which boats were assumed to have fished even though they made no deliveries are indicated by the presence of the letter "a."

Deduction for Non-Scouting Time

Before computing the average catch per boat per night, it was necessary to make certain deductions from the number of boat-nights presumably expended. In the absence of information on the number of boats fishing each night, it was assumed that the same number of boats fished each night in a lunar week, the number for the week being determined as described above.

Some of the boats in the fleet occasionally caught species of fish other than sardines. Since these boats were fishing primarily for sardines, it was assumed that the schools of other species were sighted incidentally to scouting for sardine schools, at times distributed at random through the scouting period. With such a random distribution, the average time of sighting a school of another species would be the middle of the scouting period, and one-half of a night's scouting would be lost from the effort expended toward sighting sardines. Therefore, one-half night was deducted from the total scouting time for each delivery of fish other than sardines. Following similar reasoning, one-fourth night was deducted for each catch composed partly of sardines and partly of other species.

Tabulation of number of deliveries by each boat and week of the season of 1935-36, San Francisco, as an example of the method of counting the weekly total number of boats fishing. The letter "a" indicates the boats that were considered actively fishing during the week and included in the count although no deliveries were made

Boat number	Lunar month																													
	196				197				198				199				200				201				202				203			
	Lunar week				Lunar week				Lunar week				Lunar week				Lunar week				Lunar week				Lunar week				Lunar week			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1				4	3	4	5	3	3	3	2	3	3	4	4	4	1	4	1			4	3	1								
2				2	2	2	4	5	2	5	2	7	3	6	4	4	5	8	a	4	a	11	7	2			3	1				
3																4	3	2	a	1	a	5	2	1								
4																2	3	2	a	1	a	6	1									
5					3	4	4	2	2	3	2	2	1	3	3	2	2	5	a	2	a	5	2	2			4					
6							1	3	2	3	2	3	3	4	3	3	2	3	a	2	a	4	5	2			2	1				
7					3	4	3	4	2	3	3	3	5	4	2	2	3	3	2	2	a	4	4	2								
8				2	3	4	5	4	2	5	2	4	3	3	2	3	4	2	a	3	a	4	3	1			2					
9						2	5	5	2	2	3	2	2	5	3	2	1	5	a	2	a	5	3	1			4	2				
10																																
11					1	2	4	4	2	4	3	3	3	3	2	2	4	5	1	3	a	4	5	1			3					
12				3	2	4	5	4	3	4	3	4	3	3	3	4	3	2	1	1	a	6	4	1	a	2	2	3				
13					1	3	3	4	1	3	2	3	3	3	2	2	3	5	1			5	4				4	3	1			
14				2	2	5	5	4	2	3	3	3	3	3	3	5	3	3	3	2	1	4	4	1			3	3				
15					3	3	4	4																								
16							4	3	2	3	4	4	3	4																		
17																																
18			3	4	5	6	4	5	3	3	3	3	3	5	3	5	4	3	1	2			6	a	1	3	5	5	2	1		
19					2	3			2	3	1	4	2	3	1	2	3	4	1			5	6	1	a	1	4	2				
20					3	2	6	6	2	4	1	3	3	4	4	3	1	4	a	1	a	6	4	2			3	1				
21				2	1	4	3	6	1	4	3	2	3	3	3	1	2	1	a	2	a	7	3	1	a	1	3	2				
22				1	3	5	5	6	3	4	3	4	3	4	2	3	2	3	a	2	a	6	4	1			4	3				
23				2	1	4	2	2	1	2																		1				
24					2	1	5	6	1	2	1	4	2	3	4	1	1	3	a	1	a	4	3	2	a	1	3	1				
25																							1			2	2	3				
26				6	2	5	3	4	2														3					1				
27				2	2	4	5	5	2	4	1	4	3	4	1	6	4	4	a	2	a	6	4	2	a	3	4	3				
28			3	3	4	3	2	3	3	3	2	1	2	4	2	3	4	2	1			5	5			1	3	1				
29				1	2	5	4	6	3	3	2	4	3	4	3	3	2	2	a	2	a	5	3	2			1	3				
30				2	3	4	5	5	1	3	2	4	3	1	2	3	2	2	1	3	a	6	5			3	5	3				
31					2	3	5	4	2	4	1	2	3	4	1	2	4					2	5	1	a	3	4					
32				4	5	4	4	2	2	3	2	3	2	5	2	3	4	3		1			4	2	1	2	3	2	2	1		
33																										1	1					
34					1	4	5	4	3	2	4	3	3	4	3	3	3	3	1	1			3	2	1	2	3	4	2			
35				2	2	5	4	5	4	6	3	4	3	4	3	4	2	3	a	2	1	7	5	1	a	1	3	4				
Number of boats fishing			2	16	26	27	28	28	28	27	26	26	26	26	25	27	27	26	25	22	19	24	29	23	10	14	25	22	4	2		

TABLE 21

Computation of average catch per-boat-night, Monterey, lunar month 171, season 1933-34

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Date (1933)	[1]Number of landings of sardines	Per cent of night not spent scouting for sardines	Number of boat-nights not spent scouting for sardines	[1]Number of landings of other species	Number of boat-nights scouting for other species	Total number of boat-nights lost	Estimated number of boat-nights spent	Corrected number of boat-nights spent	Total landings, 1,000 lb.	Catch per boat-night, 1,000 lb.
			(2) x (3)/100		(5)/2	(4)+(6)		(8) — (7)		(10)/(9)
August 6	.0	24.0	.0	.0	.0	.0	22	22.0	0	.0
August 7	.0	24.0	.0	1.0	.5	.5	22	21.5	0	.0
August 8	.5	24.0	.1	1.5	.8	.9	22	21.1	1	.0
August 9	.0	24.0	.0	1.0	.5	.5	22	21.5	0	.0
August 10	1.0	24.0	.2	.0	.0	.2	22	21.8	22	1.0
August 11	6.0	24.0	1.4	1.0	.5	1.9	22	20.1	98	4.9
August 12	14.0	24.0	3.4	.0	.0	3.4	22	18.6	315	16.9
August 13	10.0	24.0	2.4	.0	.0	2.4	22	19.6	291	14.8
August 14	10.0	31.8	3.2	.0	.0	3.2	30	26.8	340	12.7
August 15	20.0	31.8	6.4	1.0	.5	6.9	30	23.1	1,642	71.1
August 16	17.0	31.8	5.4	2.0	1.0	6.4	30	23.6	1,604	68.0
August 17	21.0	31.8	6.7	1.0	.5	7.2	30	22.8	1,319	57.8
August 18	10.0	31.8	3.2	1.0	.5	3.7	30	26.3	520	19.8
August 19	18.0	31.8	5.7	.0	.0	5.7	30	24.3	1,478	60.8
August 20	7.0	31.8	2.2	.0	.0	2.2	30	27.8	329	11.8
August 21	24.0	52.8	12.7	.0	.0	12.7	35	22.3	1,709	76.6
August 22	30.0	52.8	15.8	.0	.0	15.8	35	19.2	2,822	147.0
August 23	29.0	52.8	15.3	.0	.0	15.3	35	19.7	2,379	120.8
August 24	29.5	52.8	15.6	.5	.2	15.8	35	19.2	1,654	86.1
August 25	20.5	52.8	10.8	.5	.2	11.0	35	24.0	1,199	50.0
August 26	15.0	52.8	7.9	.0	.0	7.9	35	27.1	762	28.1
August 27	10.0	52.8	5.3	.0	.0	5.3	35	29.7	516	17.4
August 28	18.5	46.4	8.6	.5	.2	8.8	34	25.2	610	24.2
August 29	21.5	46.4	10.0	.5	.2	10.2	34	23.8	1,559	65.5
August 30	16.5	46.4	7.7	1.5	.8	8.5	34	25.5	910	35.7
August 31	17.0	46.4	7.9	.0	.0	7.9	34	26.1	1,267	48.5
September 1	16.0	46.4	7.4	1.0	.5	7.9	34	26.1	1,359	52.1
September 2	11.0	46.4	5.1	.0	.0	5.1	34	28.9	607	21.0
September 3	1.0	46.4	.5	.0	.0	.5	34	33.5	24	.7
September 4	.0	46.4	.0	.0	.0	.0	34	34.0	0	.0

[1] Landings composed partly of sardines and partly of other species are split equally between these two columns.

In addition to time lost incident to catching other species of fish, the total amount of scouting time expended by the fleet each night was reduced by the setting and brailing operations and by boats which terminated scouting before the end of the available scouting period. These effects are covered under "*Calculations of Percentages of Available Time Spent Scouting.*" By subtracting the percentage of time spent scouting (as determined for the lunar week) from 100, the percentage of time *not* spent scouting was obtained. By applying this percentage to the number of landings for each date, the amount of time lost from scouting was computed. (Table 21, columns 2-4.) This, of course, was done under the assumption that the boats which fished, but did not make landings, spent 100 per cent of the available time in scouting.

Procedure

The steps followed in computing the average daily catch per boat-night are shown in table 21, which covers one lunar month for one season at one port. The calendar of days for the given lunar month, determined as described under *"The Lunar Month Calendar,"* is entered in column (1).

For each day, the number of landings of sardines, the number of landings of other species of fish, and the total landings of sardines for the selected fishing fleet, were recorded in columns (2), (5), and (10) respectively. These catch data were then compared with lists of Sundays, holidays, strikes, and other possible layup periods. By inspection of the catches of these and adjacent periods it could be determined whether or not the cause in question produced a complete or partial layup. Wherever a layup was indicated, the day or days in question were eliminated from the analysis. In some instances it seemed probable that small catches made on layup dates should have been recorded against adjacent dates, and these changes were made in the records. The lunar month covered by table 21 does not happen to contain any such layup periods.

The percentage of each night *not* spent scouting for sardines was entered in column (3), this percentage being determined as described under *"Deductions for Non-Scouting Time."* Since these percentages were determined in units of lunar weeks, the figures in column (3) are identical throughout each lunar week. The percentages were applied to the numbers of landings to obtain the numbers of nights not spent scouting as given in column (4).

The numbers of landings of other species in column (5) were divided by two to determine the numbers of boat-nights spent scouting for other species given in column (6). This computation also is described under *"Deductions for Non-Scouting Time."*

The figures in column (4) were added to the comparable ones in column (6) to obtain the total number of boat-nights lost from scouting for sardines, as recorded in column (7).

In column (8) are recorded the estimated numbers of boat-nights expended by the fleet for the night preceding each landing date. This estimation involves the assumption that each boat spent one night scouting for each day of each lunar week during which it fished. As explained under *"Determination of Number of Boats Fishing"* the number of boats fishing was determined in units of one lunar week. Thus for each night the number of boat-nights expended is equal to the number of boats assumed to be fishing for the lunar week. The entries in column (8) are therefore identical throughout each lunar week, and are equal to the number of boats fishing for each lunar week.

In order to account for the time lost from scouting, each entry in column (7) was subtracted from the corresponding entry in column (8) and the result recorded in column (9).

Finally, the total landings given in column (10) were divided by the corresponding numbers of boat-nights spent, in column (9), to obtain the average catch per-boat-night, as recorded in column (11). These data were the ones used in the computations to be described in the next section.

Determination of, and Adjustment for, Effect of Lunar and Weather Conditions on Catch Per-Boat-Night

Effect of Monthly Changes in Length of Period of Darkness

The catch near the beginning and end of each lunar month is decreased as a result of the shorter hours of darkness available for fishing as compared with the center of the month. To avoid the extremely time-consuming operations which would be involved in reckoning the number of hours of darkness available each night, the nights were evaluated with respect to available hours of darkness according to their position in the lunar month. This was done by assigning each day in the lunar month a number, according to the system described under "*Available Scouting Time.*" In grouping the data for correlation, all lunar days of the same number were treated alike regardless of their sign.

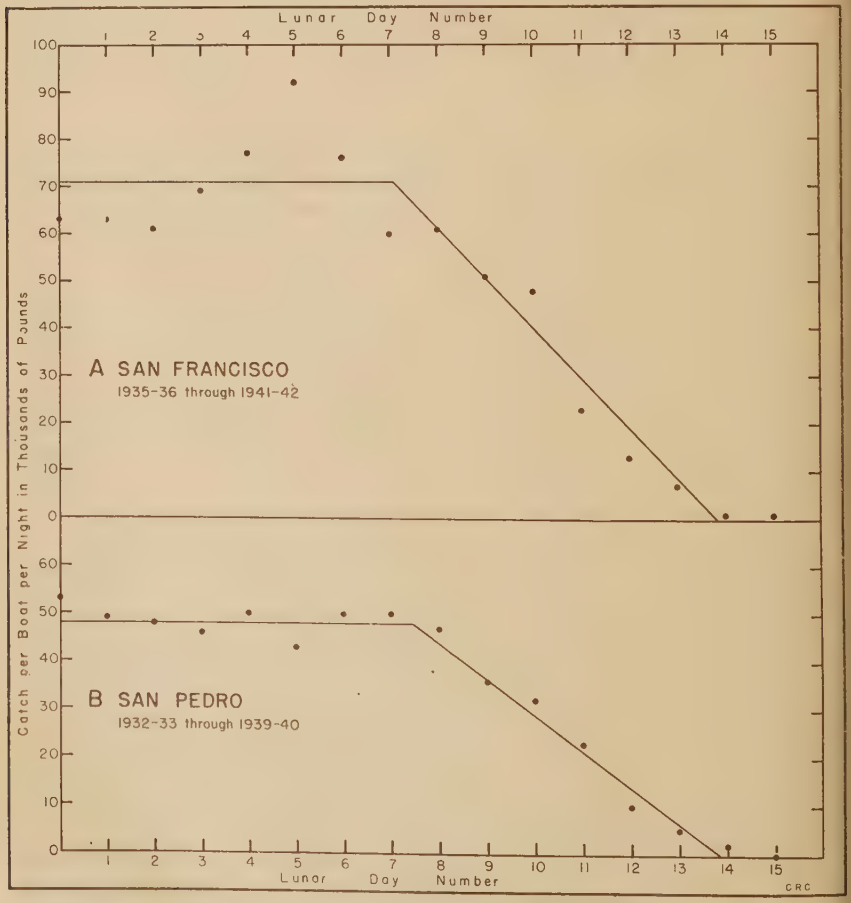

FIGURE 18. Relationship between lunar day number and average catch per-boat-night. Points shown represent averages over the indicated seasons for each lunar day. Horizontal lines represent mean catch for days 0-7. Sloped regression lines are least squares fits to points for days 8-15, each point weighted according to number of observations.

At San Pedro and San Francisco, the decrease in length of period of darkness apparently had no important effect on the average catch out to the seventh lunar day. From lunar day 8 to lunar day 15 the slope of the regression of average catch on lunar day number was quite steep. Thus the regression of average catch on lunar day number, from the center of the lunar month out to the ends, could be represented by a horizontal line for lunar days 0-7, and a sloped line for lunar days 8-15 (Fig. 18).

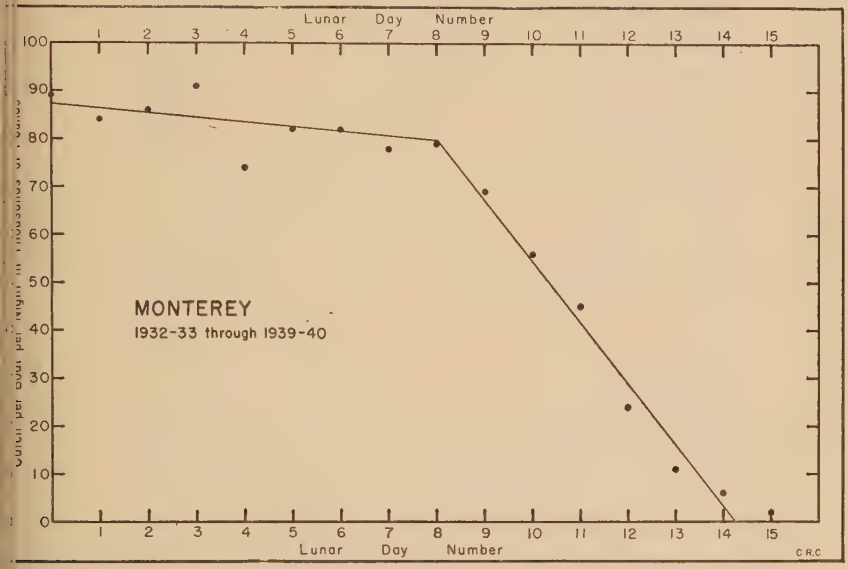

FIGURE 19. Relationship between lunar day number and average catch per-boat-night, Monterey, 1932-33 through 1939-40. Points shown represent averages for each lunar day. Regression lines are least squares fits to days 0-8 and 9-15, each point weighted according to number of observations.

The situation at Monterey was somewhat different. There the average catch fell off moderately for lunar days 0-8, and much more rapidly for lunar days 9-15. This abrupt change in slope of the regression necessitated breaking it into two parts, represented by two straight lines of different slopes (Fig. 19).

Effect of Wind

To appraise the effect of wind upon the average catch, trial regressions of catch on a number of meteorological observations were made. The variables found most satisfactory over the entire period and area covered in the analysis were the daily wind forces and directions as inferred from the daily weather maps described under *"Weather Records."*

Barometric pressures were interpolated between isobars on the weather maps for each of eight points off the coast of California for each day involved in the analysis. These eight points consisted of two groups of four—one group off southern California used for correlation with the San Pedro data, and the other off central California used for correlation with the Monterey and San Francisco data. Each group of

FIGURE 20. Location of points used in computing resultant winds from barometric pressures. Vector diagram in upper right hand corner shows method of combining pressure gradients to determine wind force and direction (taking account of the effect of the earth's rotation and of friction with the sea surface), where P=barometric pressure and subscripts indicate points on southern California square. Hatched areas show approximate sardine fishing grounds.

four points represented the corners of a square 300 nautical miles on a side, as shown in figure 20. These squares were oriented so that the pressure gradients between opposite sides would produce resultant winds perpendicular or parallel to the general trend of the coastline, taking account of the effect of the earth's rotation. In computing the gradients between sides AB and CD (Fig. 20) only points B and C were used, since points A and D were so far from the fishing grounds. The two gradients gave for each square two vectors each day, representing the wind components perpendicular and parallel to the general trend of the coast line. The resultant of these two vectors represented the wind force and direction for the day (taking account of the effect of the earth's rotation and friction with the sea surface) as illustrated in figure 20, upper right.

It was found that, for all three ports, the average catch decreased as wind force increased. This relationship could be fairly well approximated by a simple straight-line regression (Fig. 21).

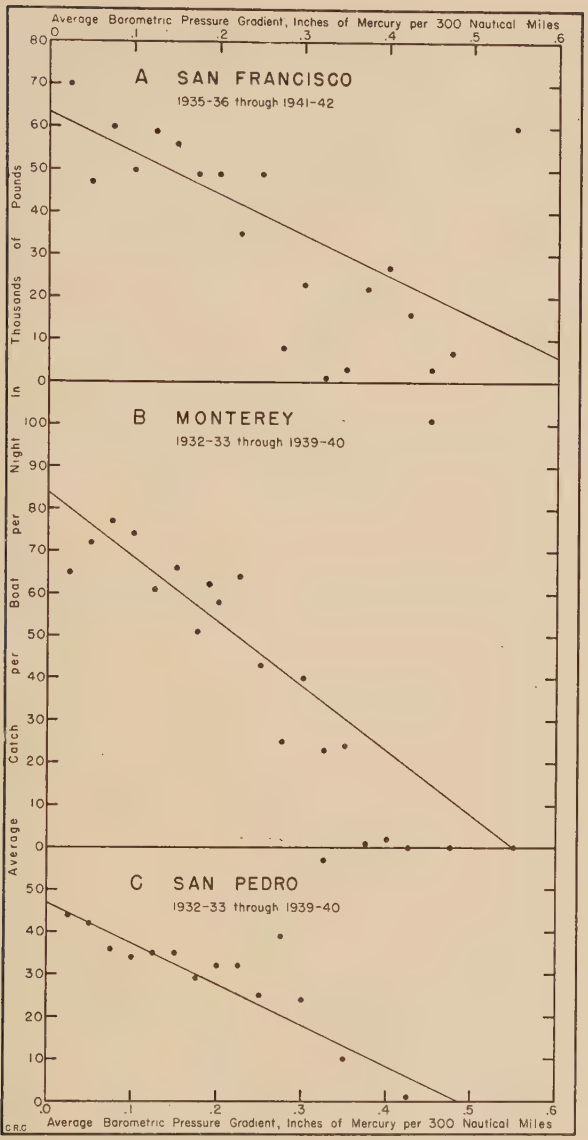
Average Barometric Pressure Gradient, Inches of Mercury per 300 Nautical Miles
A SAN FRANCISCO
1935-36 through 1941-42
B MONTEREY
1932-33 through 1939-40
C SAN PEDRO
1932-33 through 1939-40
Average Catch per Boat per Night In Thousands of Pounds
C.R.C.
Average Barometric Pressure Gradient, Inches of Mercury per 300 Nautical Miles

FIGURE 21. Relationship between barometric pressure gradients and catch per-boat-night. Points shown represent averages over the indicated seasons. A pressure gradient of 1 inch per 300 nautical miles would produce a wind of about 92 land miles per hour at San Pedro and about 81 per hour at Monterey and San Francisco. Regression lines are derived from multiple correlation analysis described in text. Small numbers of observations represented by the points near the right end of the curves account for their wide departures from the lines, since each point is weighted according to the number of observations it represents.

Wind direction proved to have an effect on average catch which could be represented by a sine curve relationship, once around the compass rose representing one complete cycle of the sine curve (Fig. 22). This relationship was converted to a rectilinear one by using the sines of the directions (coded to avoid decimals and negative numbers), instead of the directions themselves, to correlate with average catch.

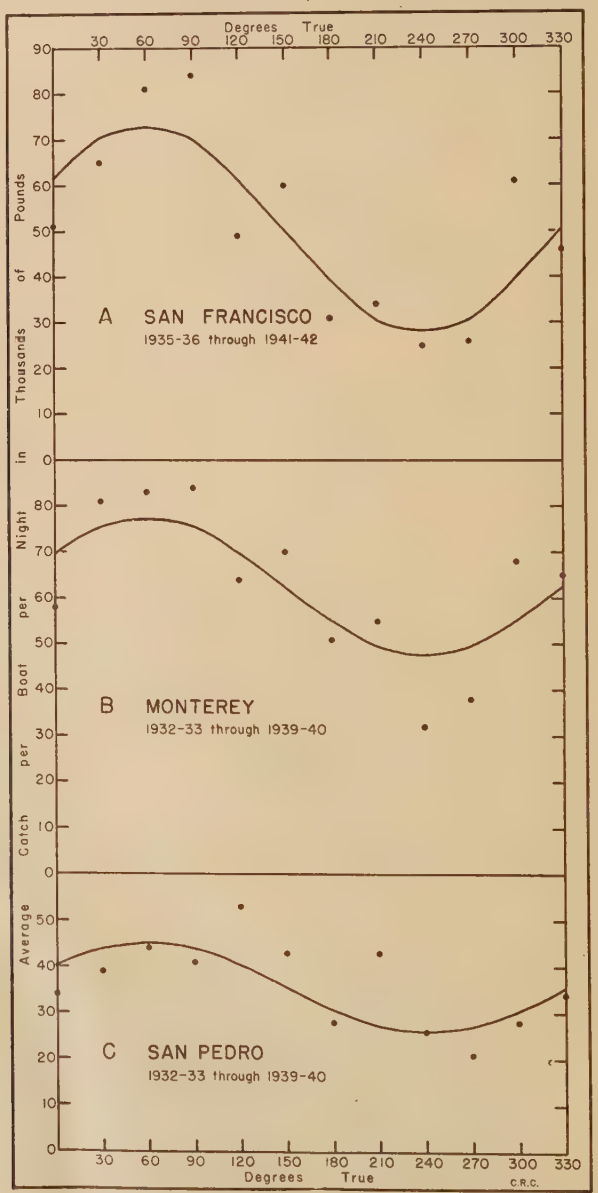

FIGURE 22. Relation between catch per-boat-night and wind direction as inferred from barometric pressure gradients. Points represent averages over indicated seasons. Sine curves were derived from multiple correlation analysis described in text.

Correlations

It was desired, for purposes of adjusting the catch figures, to obtain a simultaneous expression of the effect on average catch of lunar day number, wind force, and wind direction. This was done by means of multiple correlation analysis. A requirement for using this method is that all of the independent variables used must bear a rectilinear relationship to the dependent variable (which would be average catch per-boat-night in the present instance). It is seen from the description above that this requirement is satisfied for sine of wind direction and for wind force. It is also satisfied for lunar day number if lunar days 0-7 for San Pedro, 0-8 for Monterey, and 0-7 for San Francisco are used.

The present catch per-unit analysis was originally intended to cover only the seasons 1932-33 through 1939-40 for San Pedro and Monterey; the 1940-41 and 1941-42 seasons for those ports and the 1935-36 through 1941-42 seasons for San Francisco being added after completion of the San Pedro and Monterey weather and lunar correlations. Thus the correlations for San Pedro and Monterey include data for only the first eight seasons of the analysis, while the San Francisco correlations cover the period 1935-36 through 1941-42.

Completion of the multiple correlation analyses provided for each port an equation with which could be computed, for lunar days 0 to 7 or 8, a catch per-boat-night for any given set of weather and lunar conditions, as follows: for San Pedro $C_I = 47.9 - .969p + .952s$; for Monterey $C_I = 93.0 - .970d - 1.522p + 1.477s$; and for San Francisco $C_I = 58.3 - .954p + 2.204s$. In these formulae C_I = catch/boat/day in 1000 lb. units; d = lunar day number; p = barometric pressure gradient in 100th of an inch of mercury per 300 nautical miles; and s = sine of wind direction, expressed as 10 [sine (°True — 330°) + 1.0]. The catch so computed represented the average response, during the period of the correlations, of catch per-boat-night to the weather and lunar conditions in question. It will hereafter be referred to as the "indicated catch."

Adjustments

The adjustment of catch per-boat-night to account for the effect of lunar and weather conditions was based on the assumption that this effect would be measured by the ratio between the "indicated catch" and the average catch per-boat-night for the entire period of the correlation. This does not hold strictly true for a single day, since the catch does not always respond in exactly the same way to a given set of weather conditions. However, *on the average,* adjustments based on this assumption tend to remove from the data the effect of weather and lunar conditions on catch. Also, even on individual days the adjustment removes this effect to some extent.

Derivation of the adjustment factors may be expressed algebraically. Let C_I represent the indicated catch for an individual day and $\overline{C}$ the grand mean catch per-boat-night for the entire period of the correlation. $\frac{C_I}{\overline{C}}$ then represents the effect of weather and lunar conditions on catch and the reciprocal of this, $\frac{\overline{C}}{C_I}$ is the factor by which the catch per-boat-night must be multiplied to remove the effect. If C_O is the observed catch per-boat-night and C_A the adjusted catch per-boat-night, then

$$C_A = C_o \times \frac{\overline{C}}{C_I}$$

For lunar days 0-7 at San Pedro, 0-8 at Monterey, and 0-7 at San Francisco, C_I was computed directly from the multiple correlation equations. The other lunar days were not covered in the correlations and their C_I values had to be calculated by a special process.[1] First, a simple linear regression of catch per-boat-night on lunar day number was worked out for the lunar days not covered in the multiple correlations. Two points of intersection for these lines were then determined: (1) with the regression line for the lunar days covered in the multiple correlations, determined from the constants given in the multiple correlation equations; (2) with the baseline. The indicated catch for the lunar day number represented by intersection (1) for any combination of wind force and direction could be determined from the multiple correlation equations. It was assumed that the indicated catch for any lunar day between the two intersections would be the indicated catch for the lunar day number represented by intersection (1), reduced by the ratio between the number of days from the given lunar day to intersection (2) and the number of days between the two intersections.

The computations just described may be illustrated by an example. For Monterey intersection (1) occurred at lunar day 8.1 and (2) at 14.3 (Fig. 19). The indicated catch for a certain combination of wind force and direction at lunar day 8.1 was 79,400 pounds per boat-night. We wish to find the indicated catch for lunar day 11. $14.3 - 11 = 3.3$ and $14.3 - 8.1 = 6.2$, $\frac{3.3}{6.2} = .532$ and $C_I = .532 \times 79{,}400 = 42{,}300$.

[1] This was done to avoid making a separate multiple correlation for the remaining lunar days, which would have been a very time-consuming operation.

TABLE 22

"Indicated catches" for various weather and lunar conditions, in 1000's of lbs., as derived from multiple correlation of catch per-boat-night with lunar date, wind direction and wind force, San Francisco, 1935-36 to 1941-42. Grand mean catch for the seven season period was 55,000 lbs. Fuller explanation in text

Wind velocity, miles per hour[1]	Lunar day number	Wind direction, degrees true[2]						
		50-70	20- 40 80-100	350- 10 110-130	320-340 140-160	290-310 170-190	260-280 200-220	230-250
.0- 4.6	0–7	99	96	88	77	66	57	55
	8	85	83	76	66	57	49	47
	9	71	69	63	55	47	41	39
	10	56	55	50	44	37	32	31
	11	42	41	37	32	28	24	23
	12	27	27	24	21	18	16	15
	13	13	13	11	10	9	7	7
4.7- 8.4	0–7	94	92	83	72	61	52	50
	8	81	79	72	62	53	45	43
	9	67	66	59	52	44	37	36
	10	54	52	47	41	35	30	28
	11	40	39	35	30	26	22	21
	12	26	25	23	20	17	14	14
	13	12	12	11	9	8	7	7
8.5–12.0	0–7	89	87	78	67	56	47	45
	8	77	75	67	58	48	41	39
	9	64	62	56	48	40	34	32
	10	51	50	45	38	32	27	26
	11	38	37	33	28	24	20	19
	12	25	24	22	19	16	13	13
	13	12	11	10	9	7	6	6
12.1–15.7	0–7	84	82	73	62	51	43	40
	8	73	71	63	54	44	37	35
	9	60	59	53	45	37	31	29
	10	48	47	42	36	29	24	23
	11	36	35	31	26	22	18	17
	12	23	23	20	17	14	12	11
	13	11	11	10	8	7	6	5
15.8–19.4	0–7	80	77	69	58	47	38	36
	8	69	67	59	50	40	33	31
	9	57	56	49	41	33	27	26
	10	45	44	39	33	27	22	20
	11	34	33	29	24	20	16	15
	12	22	22	19	16	13	11	10
	13	10	10	9	8	6	5	5
19.5–23.1	0–7	75	73	64	53	42	33	31
	8	65	63	55	46	36	29	27
	9	54	52	46	38	30	24	22
	10	43	41	36	30	24	19	18
	11	32	31	27	22	18	14	13
	12	21	20	18	15	12	9	9
	13	10	10	8	7	5	4	4
23.2–26.8	0–7	70	68	59	48	37	28	26
	8	61	59	51	42	32	24	22
	9	50	49	42	34	27	20	19
	10	40	39	34	27	21	16	15
	11	30	29	25	20	16	12	11
	12	19	19	16	13	10	8	7
	13	9	9	8	6	5	4	3
26.9–30.5	0–7	65	63	54	43	32	23	21
	8	56	54	47	37	28	20	18
	9	47	45	39	31	23	17	15
	10	37	36	31	25	18	13	12
	11	28	27	23	18	13	10	9
	12	18	18	15	12	9	7	6
	13	9	8	7	6	4	3	3

TABLE 22—Continued

"Indicated catches" for various weather and lunar conditions, in 1000's of lbs., as derived from multiple correlation of catch per-boat-night with lunar date, wind direction and wind force, San Francisco, 1935-36 to 1941-42. Grand mean catch for the seven season period was 55,000 lbs. Fuller explanation in text

Wind velocity, miles per hour[1]	Lunar day number	Wind direction, degrees true[2]						
		50-70	20- 40 80-100	350- 10 110-130	320-340 140-160	290-310 170-190	260-280 200-220	230-250
30.6–34.2	0–7	60	58	49	38	27	19	16
	8	52	50	43	33	24	16	14
	9	43	42	35	28	20	13	12
	10	34	33	28	22	16	11	9
	11	26	25	21	16	11	8	7
	12	17	16	14	11	8	5	5
	13	8	8	6	5	4	2	2
34.3–37.9	0–7	56	53	45	34	23	14	12
	8	48	46	39	29	20	12	10
	9	40	38	32	24	16	10	8
	10	32	30	25	19	13	8	7
	11	24	23	19	14	10	6	5
	12	15	15	12	9	6	4	3
	13	7	7	6	4	3	2	2
38.0–41.6	0–7	51	49	40	29	18	9	7

[1] As estimated from barometric pressure gradients.

[2] The two direction categories for each of the five center columns represent the intersections of a given level of catch with the sine curve representing the relationship between wind direction and catch (See Figure 22). Degree categories are given to the nearest decade, which was the unit of the wind direction data used.

TABLE 23

ndicated catches" for various weather and lunar conditions, in 1000's of lbs., as derived from multiple correlation of catch-per-boat-night with lunar date, wind direction and wind force, Monterey, 1932-33 to 1939-40. Grand mean catch for the eight-season period was 67,600 lbs. Fuller explanation in text

Wind velocity, miles per hour[1]	Lunar day number	Wind direction, degrees true[2]						
		50-70	20- 40 80-100	350- 10 110-130	320-340 140-160	290-310 170-190	260-280 200-220	230-250
.0- 4.6	0–2	116	114	108	101	94	88	86
	3–5	113	112	106	98	91	85	83
	6–8	110	109	103	95	88	82	80
	9	93	92	87	80	74	69	68
	10	76	75	70	65	60	56	55
	11	58	57	54	50	46	43	42
	12	40	40	38	35	32	30	29
	13	23	23	21	20	18	17	17
.7- 8.4	0–2	108	107	101	93	86	80	78
	3–5	105	104	98	91	83	77	76
	6–8	102	101	95	88	80	74	73
	9	86	86	80	74	68	63	61
	10	70	69	65	60	55	51	50
	11	54	53	50	46	42	39	38
	12	38	37	35	32	29	27	27
	13	21	21	20	18	17	15	15
.5–12.0	0–2	100	99	93	86	78	72	71
	3–5	98	96	90	83	76	70	68
	6–8	95	93	88	80	73	67	65
	9	80	79	74	68	61	56	55
	10	65	64	60	55	50	46	45
	11	50	49	46	42	38	35	34
	12	35	34	32	29	26	24	24
	13	20	19	18	17	15	14	14
.1–15.7	0–2	93	91	86	78	71	65	63
	3–5	90	89	83	75	68	62	61
	6–8	87	86	80	72	65	59	58
	9	74	72	67	61	55	50	48
	10	60	59	55	50	44	40	39
	11	46	45	42	38	34	31	30
	12	32	32	29	26	24	22	21
	13	18	18	17	15	13	12	12
.8-19.4	0–2	85	84	78	70	63	57	56
	3–5	82	81	75	68	60	54	53
	6–8	80	78	72	65	58	52	50
	9	67	66	61	55	48	43	42
	10	54	54	49	44	39	35	34
	11	42	41	38	34	30	27	26
	12	29	29	26	24	21	19	18
	13	16	16	15	13	12	11	10
.5-23.1	0–2	78	76	70	63	56	50	48
	3–5	75	74	67	60	53	47	45
	6–8	72	71	65	57	50	44	42
	9	61	60	54	48	42	37	35
	10	49	48	44	39	34	30	29
	11	38	37	34	30	26	23	22
	12	26	26	24	21	18	16	15
	13	15	15	13	12	10	9	9
.2-26.8	0–2	70	68	63	55	48	42	40
	3–5	67	66	60	52	45	39	38
	6–8	64	63	57	50	42	36	35
	9	54	53	48	42	35	30	29
	10	44	43	39	34	28	24	23
	11	34	33	30	26	22	19	18
	12	24	23	21	18	15	13	12
	13	13	13	12	10	9	7	7

TABLE 23—Continued

"Indicated catches" for various weather and lunar conditions, in 1000's of lbs., as derived from multiple correlation of catch-per-boat-night with lunar date, wind direction and wind force, Monterey, 1932-33 to 1939-40. Grand mean catch for the eight-season period was 67,600 lbs. Fuller explanation in text

Wind velocity, miles per hour[1]	Lunar day number	Wind direction, degrees true[2]						
		50-70	20- 40 80-100	350- 10 110-130	320-340 140-160	290-310 170-190	260-280 200-220	230-250
26.9–30.5	0–2	62	61	55	48	40	34	33
	3–5	60	58	52	45	38	32	30
	6–8	57	55	49	42	35	29	27
	9	48	46	41	35	29	24	22
	10	39	38	34	28	23	19	18
	11	30	29	26	22	18	15	14
	12	21	20	18	15	12	10	10
	13	12	11	10	9	7	6	6
30.6–34.2	0–2	55	53	47	40	33	27	25
	3–5	52	51	45	37	30	24	22
	6–8	49	48	42	34	27	21	20
	9	41	40	35	28	22	17	16
	10	33	32	28	23	18	14	13
	11	26	25	22	18	14	11	10
	12	18	17	15	12	10	7	7
	13	10	10	9	7	5	4	4
34.3–37.9	0–2	47	46	40	32	25	19	18
	3–5	44	43	37	30	22	16	15
	6–8	42	40	34	27	19	14	12
	9	35	33	28	22	16	11	9
	10	28	27	23	18	13	9	8
	11	22	21	18	14	10	7	6
	12	15	14	12	10	7	5	4
	13	8	8	7	5	4	3	2
38.0–41.6	0–2	40	38	32	25	17	12	10
	3–5	37	35	30	22	15	9	7
	6–8	34	32	27	19	12	6	4

[1] As estimated from barometric pressure gradients.

[2] The two direction categories for each of the five center columns represent two intersections of a given level of catch with the sine curve representing the relationship between wind direction and catch (See Figure 22). Degree categories are given to the nearest decade, which was the unit of the wind direction data used.

TABLE 24

"Indicated catches" for various weather and lunar conditions, in 1000's of lbs., as derived from multiple correlation of catch-per-boat-night with lunar date, wind direction and wind force, San Pedro, 1932-33 to 1939-40. Grand mean catch for the eight-season period was 38,300 lbs. Fuller explanation in text

Wind velocity, miles per hour[1]	Lunar day number	Wind direction, degrees true[2]						
		50-70	20- 40 80-100	350- 10 110-130	320-340 140-160	290-310 170-190	260-280 200-220	230-250
D- 5.2	0–7	63	62	59	54	49	46	44
	8	58	57	54	50	45	42	41
	9	49	48	45	41	38	35	34
	10	39	38	36	33	30	28	27
	11	29	29	27	25	23	21	20
	12	20	19	18	17	15	14	14
	13	10	10	9	8	8	7	7
B- 9.3	0–7	58	57	54	49	44	41	39
	8	54	53	50	45	41	38	36
	9	45	44	41	38	34	31	30
	10	36	35	33	30	27	25	24
	11	27	26	25	23	20	19	18
	12	18	18	16	15	14	12	12
	13	9	9	8	8	7	6	6
4–13.5	0–7	54	52	49	44	39	36	35
	8	50	48	45	41	36	33	32
	9	41	40	38	34	30	28	27
	10	33	32	30	27	24	22	21
	11	25	24	23	20	18	16	16
	12	16	16	15	14	12	11	11
	13	8	8	8	7	6	6	5
6–17.6	0–7	49	48	44	39	34	31	30
	8	45	44	41	36	32	28	27
	9	38	36	34	30	26	24	23
	10	30	29	27	24	21	19	18
	11	22	22	20	18	16	14	14
	12	15	15	14	12	11	10	9
	13	8	7	7	6	5	5	5
7–21.7	0–7	44	43	39	34	30	26	25
	8	40	39	36	32	27	24	23
	9	34	33	30	26	23	20	19
	10	27	26	24	21	18	16	15
	11	20	20	18	16	14	12	12
	12	14	13	12	11	9	8	8
	13	7	7	6	5	5	4	4
8–25.9	0–7	39	38	34	30	25	21	20
	8	36	35	32	27	23	20	18
	9	30	29	26	23	19	16	15
	10	24	23	21	18	15	13	12
	11	18	18	16	14	12	10	9
	12	12	12	11	9	8	6	6
	13	6	6	5	4	4	3	3
0–30.0	0–7	34	33	30	25	20	16	15
	8	32	30	27	23	18	15	14
	9	26	25	23	19	15	13	12
	10	21	20	18	15	12	10	9
	11	16	15	14	11	9	8	7
	12	11	10	9	8	6	5	5
	13	5	5	5	4	3	3	2
1–34.2	0–7	29	28	25	20	15	12	10
	8	27	26	23	18	14	11	10
	9	23	22	19	15	12	9	8
	10	18	17	15	12	9	7	6
	11	14	13	12	9	7	5	5
	12	9	9	8	6	5	4	3
	13	5	4	4	3	2	2	2
3–38.3	0–7	24	23	20	15	10	7	6
	8	23	22	18	14	10	6	5
	9	19	18	15	12	8	5	4
	10	15	14	12	9	6	4	3
	11	11	11	9	7	5	3	3
	12	8	7	6	5	3	2	2
	13	4	4	3	2	2	1	1

[1] As estimated from barometric pressure gradients.

[2] The two direction categories for each of the five center columns represent the intersections of a given level of catch th the sine curve representing the relationship between wind direction and catch (See Figure 22). Degree categories e given to the nearest decade, which was the unit of the wind direction data used.

In actual practice the indicated catches were not computed for every separate day, but were found from tables of indicated catches (Tables 22, 23, and 24). These tables were constructed with class intervals large enough to keep their size reasonable, but fine enough to reflect significant details of the regressions.

Adjustment factors as described so far have been for individual days, but it was necessary to have lunar week factors also, for use in the computations of within- and between-season changes. These factors were derived in the same manner as the daily factors, except that the C_I value was replaced by the sum of the C_I values for all the days in the week and $\overline{C}$ was multiplied by 6,[1] placing the computation on the basis of a standard 6-day week. Algebraically, letting C_{aw} be the adjusted lunar weekly catch, C_{ow} the observed lunar weekly catch, and ${}^{c}I_1$, ${}^{c}I_2$, et cetera, the indicated catches for individual days of the week of n days:

$$C_{aw} = C_{ow} \times \frac{6\,\overline{C}}{{}^{c}I_1 + {}^{c}I_2 + {}^{c}I_3 \ldots {}^{c}I_n}$$

Near the ends of the lunar month, catches were so rare and adjustment factors so large that application of the latter would have introduced an excessive amount of random variability into the data. Therefore, lunar days 14 and 15 were completely eliminated from the computation of catch per unit of effort.

Calculation of Between-Season Changes

Linkage of Lunar Weeks

In computing the season to season changes in catch per-unit, it was necessary in some manner to eliminate the effect of differences in size and efficiency of boats. This was done by comparing the performance of a group of boats in one year with the performance of the same group in the next year. Then a new group for the next year was selected to compare with the following year, and so on.

This linkage was done in units of one lunar week. Each lunar week in one season was compared with the comparable lunar week in the following season. Comparability of weeks was determined by matching fishing seasons so that, as nearly as possible, the same parts of the calendar year were compared. A schedule of comparable lunar weeks conforming to this rule is given in table 15, where any lunar week is compared with the weeks adjacent to it on the same line of the table. For convenience, the names of the calendar months most closely corresponding to them have been used as designations for the lunar months, and are given in the stub of table 15. This follows the system set up by Clark (1939: Table 2).

Procedure

An example (covering part of the comparison for two adjacent seasons at one port) of the procedure in computing between-season changes in catch-per-unit of effort is given in table 25. The numbers of the lunar weeks which are to be linked are given in column (1). Each pair of lunar weeks includes one week of the first season (1934-35) involved, and

[1] During the early seasons at Monterey, and during the entire period of the analysis at San Francisco, the Sunday holiday was not observed. However, the 6-day week was adopted as the standard, since the majority of the data were on that basis.

the corresponding week of the second season (1935-36). For each week the number of sardine landings was recorded in column (2). In column (3) the average percentage of time *not* spent scouting was entered, as described under *"Deductions for Non-Scouting Time."* This percentage was applied to the figures in column (2) to obtain the number of nights not spent scouting for sardines, which was entered in column (4). In column (5) the numbers of landings of other species of fish for each week were entered. These figures were divided by 2 to obtain the numbers of nights spent scouting for other species of fish (as explained under

Table 25

Computation of between-season changes in catch per-boat-week, Monterey, 1934-35 season compared with 1935-36 season.

(1) Lunar week number	(2) Number of sardine landings	(3) Per cent of time not spent scouting for sardines	(4) Number of boat-nights not spent scouting for sardines: (2) x (3) / 100	(5) Number of landings of other species	(6) Number of boat-nights scouting for other species: (5)/2	(7) Total number of boat-nights lost: (4) + (6)	(8) Number of nights in week	(9) Number of boat-weeks lost: (7)/(8)	(10) Estimated number of boat-weeks spent	(11) Corrected number of boat-weeks spent: (10)—(9)	(12) Total landings 1,000 lb.	(13) Lunar and weather adjustment factor	(14) Adjusted total landings 1,000 lb.: (12) x (13)	(15) Catch per boat-week 1,000 lb.: (14)/(11)
183-2	9.0	26.3	2.4	.0	.0	2.4	3	.8	5	4.2	110	1.555	171	41
196-2	8.0	28.2	2.3	.0	.0	2.3	6	.4	5	4.6	312	.856	267	58
183-3	45.0	61.3	27.6	3.0	1.5	29.1	7	4.2	17	12.8	3,986	.742	2,958	231
196-3	52.0	42.3	22.0	5.0	2.5	24.5	6	4.1	17	12.9	3,238	.730	2,364	183
183-4	161.5	58.1	93.9	1.5	.8	94.7	7	13.5	22	8.5	15,056	1.180	17,766	2,090
196-4	98.5	64.4	63.5	4.5	2.2	65.7	6	11.0	22	11.0	7,351	1.160	8,527	775
184-1	121.5	55.8	67.8	1.5	.8	68.6	6	11.4	28	16.6	12,830	1.327	17,025	1,026
197-1	60.5	28.2	17.1	9.5	4.8	21.9	5	4.4	28	23.6	3,789	1.482	5,615	238
184-2	185.5	51.5	95.5	1.5	.8	96.3	6	16.0	33	17.0	20,844	.779	16,237	955
197-2	154.0	48.9	75.4	4.0	2.0	77.4	6	12.9	33	20.1	11,511	.777	8,944	445
184-3	155.0	38.4	59.5	11.0	5.5	65.0	6	10.8	40	29.2	13,297	.805	10,704	366
197-3	176.5	53.4	94.2	4.5	2.2	96.4	6	16.1	40	23.9	13,841	.777	10,754	450
184-4	174.5	58.2	101.7	5.5	2.8	104.5	6	17.4	40	22.6	17,187	1.515	26,038	1,152
197-4	167.0	58.5	97.6	15.0	7.5	105.1	6	17.5	40	22.5	14,619	1.335	19,516	867
185-1	78.0	24.0	18.7	4.0	2.0	20.7	5	4.1	39	34.9	6,541	1.933	12,644	362
198-1	88.0	34.1	30.0	.0	.0	30.0	6	5.0	39	34.0	7,311	1.345	9,833	289
185-2	177.5	44.5	79.0	4.5	2.2	81.2	6	13.5	36	22.5	19,746	.695	13,723	610
198-2	94.0	45.9	43.2	.0	.0	43.2	6	7.2	36	28.8	10,489	.752	7,888	274
185-3	195.5	69.1	135.0	4.5	2.2	137.2	6	22.9	41	18.1	20,166	.746	15,044	831
198-3	55.0	31.2	17.2	.0	.0	17.2	6	2.9	41	38.1	5,581	.815	4,549	119
185-4	174.5	47.3	82.5	2.5	1.2	83.7	6	14.0	46	32.0	14,696	1.180	17,341	542
199-4	166.0	65.4	108.5	1.0	.5	109.0	6	18.2	46	27.8	17,123	1.340	22,945	825
186-1	106.0	16.5	17.5	.0	.0	17.5	5	3.5	44	40.5	11,618	1.208	14,035	346
200-1	35.0	37.5	13.1	.0	.0	13.1	3	4.4	44	39.6	4,031	2.231	8,993	227
186-2	220.0	30.0	66.0	3.0	1.5	67.5	6	11.2	48	36.8	23,632	.914	21,600	587
200-2	170.0	51.0	86.7	.0	.0	86.7	6	14.4	48	33.6	16,349	1.002	16,382	488
186-3	103.5	40.6	42.0	.5	.2	42.2	6	7.0	27	20.0	11,772	.740	8,711	436
200-3	102.0	70.8	72.3	.0	.0	72.3	6	12.0	27	15.0	10,496	.882	9,257	617

[1] Landings composed partly of sardines and partly of other species are split equally between these two columns.

"Deductions for Non-Scouting Time") and the results entered in column (6). Columns (4) and (6) were added to obtain the total number of boat-nights lost from scouting, column (7).

In column (8) were recorded numbers of fishing nights in each week. Dividing the number of boat-nights lost, as recorded in column (7), by the number of nights in the week, gave the number of boat-weeks lost, as shown in column (9). The number of boat-weeks spent was estimated from the number of boats fishing, as described under *"Determination of Number of Boats Fishing."* It was assumed that each boat which fished at all fished an entire lunar week, so that the number of boat-weeks spent was the same as the number of boats assumed to have been fishing. This number was entered in column (10), and from it was subtracted the number of boat-weeks lost in column (9), giving the corrected number of boat-weeks spent, which was recorded in column (11).

The total landings of the selected fleet, in 1,000 lb. units, were entered in column (12). In column (13) the lunar and weather adjustment factors, derived as set forth under *"Adjustments"* were recorded. Each total catch in column (12) was then multiplied by the corresponding adjustment factor in column (13), and the adjusted catch set down in column (14). This adjusted catch was divided by the corrected number of boat-weeks spent, as shown in column (11), giving the adjusted catch per-boat-week, which was entered in column (15).

The series of seasons for each port was now linked. To do this all the adjusted catches per-boat-week for each season were summed. There were two such sums for each season except the first and last, one comparing the given season with the previous season, and the other comparing it with the subsequent season. This gave pairs of adjacent seasons, such as 1932-33 with 1933-34, 1933-34 with 1934-35, et cetera. For each such pair of seasons, the sum of the catches per-boat-week for the second of the two seasons was divided by the corresponding sum for the first season. These ratios were then used to link the successive seasons, as follows:

The average catch per-boat-week was determined for the first season of each series. Then this average was multiplied by the ratio between the performance of the same group of boats in the first and second season, as described above, giving the average catch per-boat-week for the second season. The procedure was then repeated, using the ratio between the second and third season, and so on until the end of the series. This may be expressed algebraically, letting $\overline{C}$ represent the average catch per-boat-week for each season, S the sum of the weekly catches per-boat-week, and using subscripts to refer to the seasons in the series.

$$\text{Then } \overline{C}_2 = \overline{C}_1 \frac{S_2}{S'_1},\ \overline{C}_3 = \overline{C}_2 \frac{S_3}{S'_2} \cdots \overline{C}_n = \overline{C}_{n-1} \frac{S_n}{S'_{n-1}}$$

Calculation of Within-Season Changes

Linkage of Weeks

In calculating within-season changes in catch per unit of effort, each lunar week was compared with the previous and succeeding lunar week of the same season. A group of boats fishing in both the first and second lunar weeks of a season was used to make the comparison between these two weeks. Then a new group, fishing in both the second and third lunar weeks, was used to compare them, and so on. Thus comparisons of the

performance of identical boats in pairs of adjacent lunar weeks within a season were made in the same way that comparisons were made between corresponding weeks of two adjacent seasons in the between-season change computation. To avoid the unreliability associated with very small samples, any comparisons involving less than 10 boats were eliminated from the analysis.

Procedure

With the exception of the difference in comparison of weeks mentioned above, the calculation of catch per-boat-week for within-season changes was identical with that described for the between-season changes. The series of weeks within each season were linked in exactly the same manner as the series of seasons for each port, also described under "Calculation of Between Season Changes—*Procedure.*"

The average value for catch per-boat-week for season was determined by the linked figure from the between-season change computation. To make the series of within-season weekly values for each season conform to this average, they were weighted so that their total was the same as the between-season linked figure times the number of weeks in the season. The weighting factor K may be expressed algebraically as follows: $K = \frac{n\overline{C}}{\Sigma W}$, where n = the number of weeks in the season, $\overline{C}$ = the linked catch per-boat-week figure from the between-season change computation, and ΣW = the sum of the weekly values from the within-season change computation. Each weekly value was multiplied by the factor K to obtain the weighted weekly catch per-boat-week.

Correction for Seasonal Changes in Length of Period of Darkness

The annual change in time of sunset and sunrise causes a corresponding change in the length of the period of darkness available for fishing, this period having a minimum at the time of the summer solstice in June and a maximum at the time of the winter solstice in December. This is seen by inspection of a list of the number of hours of scouting time available for each lunar month of a season representing the average of fishing seasons 1932-33 to 1941-42 at Monterey, as follows: lunar month "August," 6.26 hours; "September," 6.98 hours; "October," 7.61 hours; "November," 7.85 hours; "December," 7.98 hours; "January," 7.86 hours; "February," 7.82 hours. No month from "October" through "February" departs more than 3 per cent from the season average of 7.82 hours. Such small departures as this do not seem to warrant adjustment, in view of the general variability of the data. Lunar months "August" and "September," however, have 20 per cent and 11 per cent respectively less time available per night than the average. Using the catch per-boat-week for these without adjustment would result in values which would be too low, since they would represent catches during shorter nights than for the other lunar months of the season.

The adjustment factors for length of available time were calculated on a uniform basis for all seasons, since the effect of the change in time of sunrise and sunset would be substantially the same from year to year. Since the catch per-boat-week for lunar months "August" and "September" would be less than that for the other months in direct proportion to the lesser amount of time available, the adjustment factors were

based on the average length of period of darkness. The factor for "August" was the season average number of hours available per night, 7.82, divided by the "August" number, 6.26 hours, making the factor $\frac{7.82}{6.26} = 1.25$. Multiplying each weekly catch per-boat-week figure for lunar month "August" in each season by 1.25 brought all of these figures up to what they would have been if 7.82 instead of 6.26 hours per night had been available. Likewise, the adjustment factor for lunar month "September" was $\frac{7.82}{6.98} = 1.12$, and it was similarly applied. San Pedro figures were not adjusted for this effect, since there was no August or September fishing there.

Adjustment of Daily Catch per-Unit Figures

Daily catch per-boat-night data were desired for the purpose of weighting daily length-frequencies, and their computation is here described even though they are not used in the main text of this paper.

Table 26

Adjustment of daily catch per-boat-night figures. Monterey, 1932-33, Lunar Month 160.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Date	Catch per boat-night, 1,000 lb.	Lunar and weather adjustment factor	Adjusted catch per boat-night, (2) x (3)	Catch per boat-week	Weighting factor	Weighted catch per boat-night, (6) x (4)
September 17	0	4.39	0			0
September 18	19	1.94	37			48
September 19	80	1.99	159			206
September 20	55	1.53	84			109
September 21	94	1.11	104			134
September 22	86	.93	80			103
Totals			464	600	1.293	
September 23	86	.66	57			60
September 24	121	.77	93			98
September 25	72	.75	54			57
September 26	56	.90	50			53
September 27	55	1.28	70			74
September 28	97	.96	93			98
September 29	51	1.07	55			58
Totals			472	497	1.053	
September 30	227	.85	193			199
October 1	131	.85	111			115
October 2	75	.73	55			57
October 3	254	.69	175			181
October 4	136	.81	110			114
October 5	124	.69	86			89
October 6	172	.82	141			146
Totals			871	899	1.032	
October 7	107	.93	100			115
October 8	83	1.18	98			113
October 9	51	1.24	63			72
October 10	62	.97	60			69
October 11	41	1.73	71			82
October 12	44	1.98	87			100
October 13	9	3.72	33			38
Totals			512	589	1.150	

n adjustment factor for each day was derived as described under *Adjustments''* in the section on the lunar and weather effects. Each aily catch per-boat-night figure was then multiplied by the correspondng adjustment factor.

The level of catch per-unit for each lunar week was determined by ie value from the within-season change computation. Daily catches er-boat-night were multiplied by factors which made the total for each eek the same as the catch per-boat-week value from the within-season hange computation.

An example of the working out of the above computations is given n table 26. Column (1) is a calendar scale with the days grouped into unar weeks. The catch per-boat-night, as previously computed, is given n column (2), and the lunar and weather adjustment factor for each day n column (3). In column (4) are set down the adjusted catches, resultng from multiplying each day's catch per-boat-night by the correspondng adjustment factor. Catches per-boat-week, from the within-season hanges computation, are given in column (5). Weighting factors for ach week are derived by dividing the catch per-boat-week by the total f the catches per-boat-night. For example, the weighting factor for the rst week on table 9 is $\frac{600}{464}$, or 1.293, and will be seen entered in column 6) opposite the 464 and 600. Weighting factors for the other lunar eeks are also entered in column (6). The weighted catches per-boatight are entered in column (7). They are obtained simply by multilying the adjusted catches per-boat-night in column (4) for each week y the corresponding weekly weighting factors in column (6).

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